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Red-Tide Research Summarized to 1964 Including an Annotated Bibliography

By George A. Rounsefell and Walter R. Nelson

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Frontispiece.--A representative sample of dead fish deposited on beach in the lower part of Tampa Bay during the 1963 red tide.

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ABSTRACT

This paper summarizes from published and unpublished data and reports the status of research on the Florida red tide up to 1964. It contains 292 references, mostly annotated, on red tide and closely related subjects. The relation of oceanographic conditions to red-tide blooms, the seasonal and coastwise distribution of the Florida red tide, and progress in various aspects of research are discussed.

INTRODUCTION

This summary of red-tide research is a modified version of a report prepared for the Bureau of Commercial Fisheries under Contract No. 14-17-0002-79 with the University of Alabama (Status of red-tide research in 1964, by George A. Rounsefell and Walter R. Nelson, Technical Report 64-1, Alabama Marine Resources Laboratory, 1964, 192 p., processed).

The aim of the first report was to examine and review published and unpublished papers and data relating to red tide, to summarize this material, and to make the summary available prior to a symposium on red tide called by the Bureau in October 1964. A similar symposium, held at the Bureau of Commercial Fisheries Biological Laboratory in Galveston, Tex., March 5 to 7, 1958[1], resulted in several modifications to improve the then existing research program. We hope that the 1964 symposium has also been useful in assessing current progress and suggesting promising modifications of the research program.

We began by reviewing as many of the published papers and manuscripts on red tide as could be obtained and examined in the allotted time. The list includes many references which, although not examined by us, may prove useful to anyone needing closely related information. Stress was placed on material relating to the red tide of Florida. No attempt was made to undertake a synopsis of each paper; rather the comments and excerpts given represent a deliberate attempt to bring out important facets of the research problem. Over 20 new references have been added to the 1964 report.

As a second step, the senior author is collaborating with staff members of the Bureau of Commercial Fisheries Biological Laboratory in St. Petersburg Beach, Fla., in preparing a paper based on 7 years of published raw data on red tide covering the period 1954-61 collected by the staff of the Laboratory. The data were coded, punched, and verified on nearly 13,000 ADP cards and run through the solid-state Univac-80 computer at the University of Alabama Computer Center in Tuscaloosa in preliminary analyses, some of which are presented in this report (see fig. 1).

Finally, we presented our ideas on the rationale of red-tide occurrence, together with suggestions for future research. This section of our report was presented with some trepidation in view of the expert audience at the symposium. It represented ideas gained chiefly from winnowing of the extant reports, and we hoped that the participants in the symposium would not regard it as an attempt to push our ideas, but as an attempt to furnish material for stimulating discussion.

Note.--George A. Rounsefell, Professor of Marine Biology, and Walter R. Nelson, Marine Biologist, University of Alabama, University, Alabama. 35486

[1] All excerpts or references from the report of this earlier symposium (mimeographed) are identified simply as (USFWS, 1958).

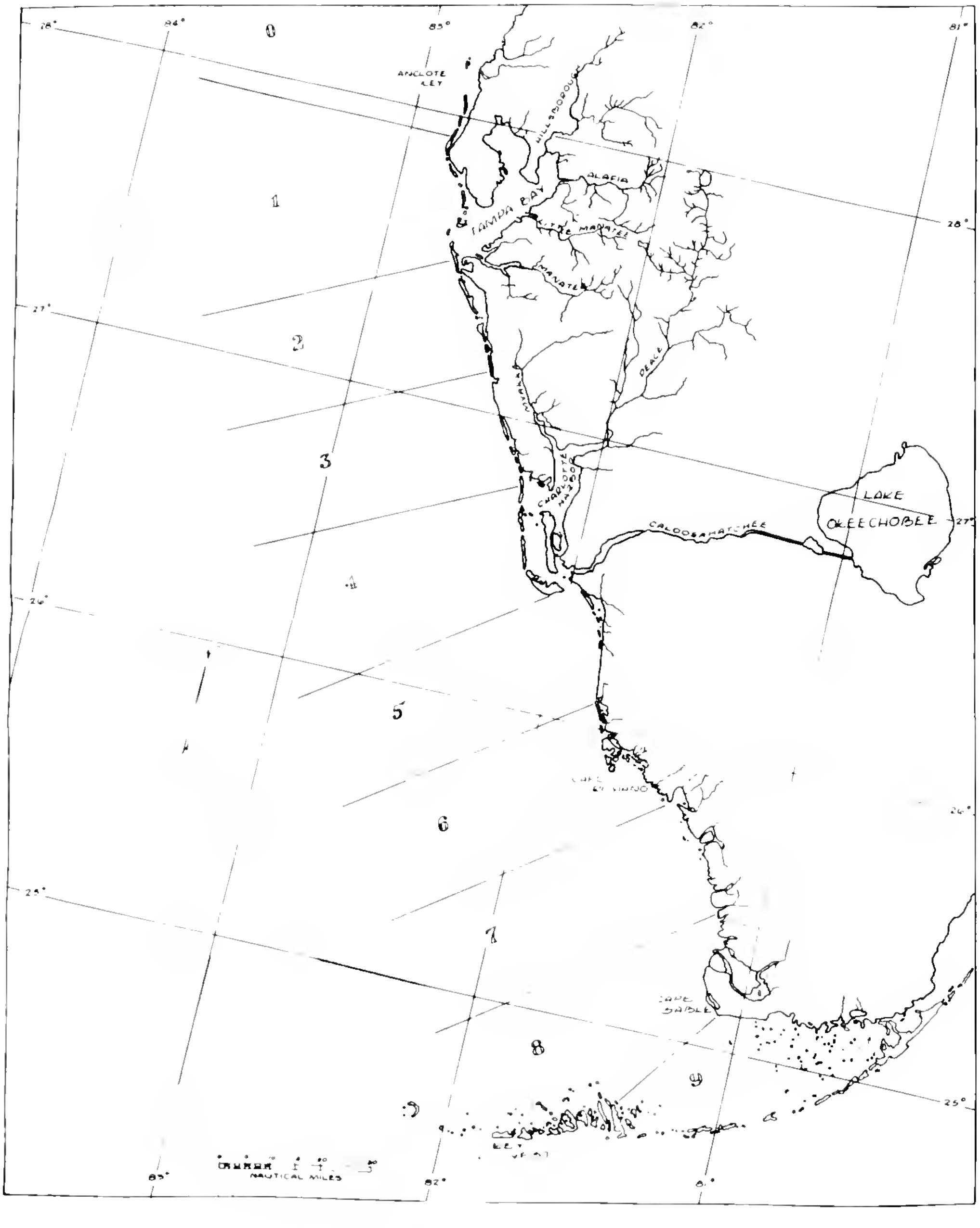

Figure 1.--North-South areas used in coding Florida red-tide data.

HISTORICAL

Red tide with its concomitant mass mortalities is not a phenomenon peculiar to Florida. Overblooming of plankton organisms has been well known since ancient times. It should suffice to note that discolored water has been observed in widely scattered seas; the Red Sea and the Gulf of California (once named the Vermilion Sea) are cases in point. Many discolorations are apparently harmless, or at least caused by nontoxic organisms, such as the tremendous blooms of the diatom Aulacodiscus kittoni at Copalis Beach, Wash. A few discolorations arise from swarms of copepods, from ciliates, or from chromogenic bacteria, but the great majority are caused by dinoflagellates, some of which are apparently only slightly toxic, if at all. They vary in color from almost transparent, through pale green and yellow, to amber and bright red. Many are luminescent; some have a definite cuticle (are armored), and many are naked. In some localities the overblooming

occurs only sporadically and reports are few. The senior author found no reports, for instance, from Alaska, although he knows from personal experience that streaks of water as red as tomato soup sometimes occur in southeastern Alaska in late summer.

The best documented reports of red tides and mass mortalities come from a few localities: The Malabar Coast of India, the coast of northern Chile and Peru, near Walvis Bay in Southwest Africa, Japan, and southern California. Additionally, in many localities in which blooms of toxic dinoflagellates are not sufficiently dense to cause mortalities, the ingested organisms can render shellfish toxic to humans.

The distribution of the naked dinoflagellate, Gymnodinium breve, that causes the Florida red tide is not well known. It occurs in Trinidad (Lackey, 1956) and is the chief suspect in frequent fish mortalities near the mouth of the Orinoco River in the Gulf of Paria. There is considerable evidence that G. breve may be distributed throughout the Gulf of Mexico. The organism has caused extensive fish mortalities along the southern coast of Texas, extending far down the Mexican coast (Wilson and Ray, 1956; Gunter, 1952; Lund, 1935). Wilson isolated G. breve from Galveston waters (Collier, 1958b). Fishermen report "red water" on the Campeche Banks, but the causative agent is still unknown (Graham, 1954). Because G. breve was not identified until 1948 and is so fragile as to resist collection by conventional methods, it may be far more widely distributed than available records indicate. Although other toxic dinoflagellates, such as Gonyaulax, occur in Florida, it is probably safe to assume that the earlier red tides were also caused by G. breve. Hutton (1956) reported a bloom of Ceratium furca with counts as high as 17,600,000 cells per liter, but this was in Hillsborough Bay (a part of Tampa Bay) which is not normally invaded by G. breve on account of the low salinity (see Ingle and Sykes, 1964).

GENERAL CONDITIONS DURING RED-TIDE OUTBREAKS

Conditions conducive to overblooming of dinoflagellates are suggested by numerous reports of red-tide outbreaks in many localities. These are discussed below.

Temperature

Red tides as a whole are less frequent and less intense in temperate regions than in the lower latitudes, where the hot weather during outbreaks is often mentioned. These observations concerning hot weather may be a reflection of other conditions, such as a lack of strong wind. Certainly the sea temperatures remain fairly low in regions of extensive upwelling, such as the California and southwest African coasts, where red tides often occur.

Barker (1935) found the optimal range for 14 species of marine dinoflagellates to lie between 18° and 35° C. For Gymnodinium breve Finucane (1960) stated that the optimum is 26° to 28° C., but that dense populations were observed at 15° to 18° C. Aldrich (1959) exposed 800 individual cultures to controlled temperatures and found no survival at 7° C. or below, or at 32° C. and above. Populations did not grow above 30° C., and multiplication was visibly slowed but not halted at 15° C.

Isopleths of abundance of G. breve against temperature and salinity (averages from samples of 20 or more) from 7 years of field data analyzed on the computer show that the organisms appear to thrive from 16° to 27° C. (fig. 2). Beyond this range organisms occurred only in low abundance. These observations agree remarkably well with the laboratory results of Aldrich (1959).

The effect of cold waves in ending a bloom has often been mentioned. After the heavy outbreak in the fall of 1957, Finucane (USFWS, 1958) said, "...There were several cold waves in December and water temperature was as low as 9.9° Centigrade. Following the cold front we couldn't find any bugs north of Pass-a-grille. ..." Taylor (1917a,b) mentioned a severe freeze in February 1917, following the heavy fall outbreak of 1916, which did not recur in 1917. Gunter (USFWS, 1958) mentioned a cold spell that brought freezing temperatures to Miami and ended (temporarily at least) the 1946 red tide outbreak.

Salinity

Dinoflagellates in general have a wide salinity tolerance. The armored species are usually

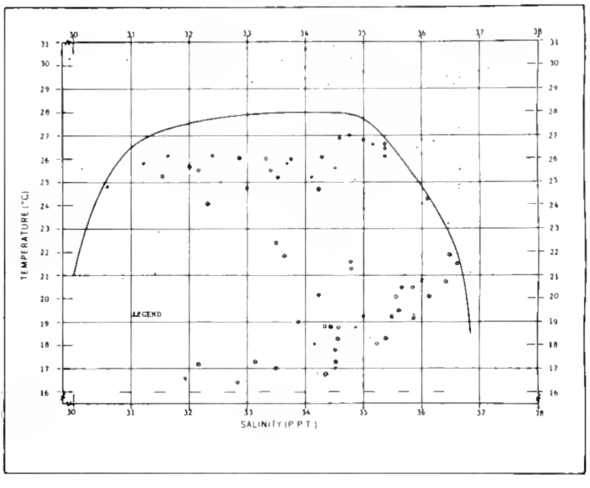

Figure 2.--Isopleth (0.01) of geometric mean of Gymnodinium breve per ml. showing relation of G. breve to temperature and salinity.

considered to be estuarine or coastal, while the naked forms are found more in the plankton of the open seas.

Gymnodinium breve is apparently not estuarine, but neritic. In controlled experiments, Aldrich and Wilson (1960) found the best growth at salinities between 27 and 37 p.p.t. (parts per thousand). Field observations indicate ranges of salinity for good growth between 31 and 37 p.p.t. From computer analysis of the 1954-61 field data we find no real abundance of the red-tide organism below 30.5 p.p.t. salinity (fig. 2). The upper limit for abundance of organisms appears to vary with temperature. The upper limit is 37 p.p.t.; growth is poor above 36 p.p.t. when temperatures exceed about 23° C.

Rainfall

Heavy rainfall is often given as a likely factor in producing red tides. Thus, Hornell (1917) mentioned the annual occurrence of red tide "after the passing of the rainy season" along the Malabar Coast. A translation of Nümann (1957) follows: "According to all reports, outbreaks of red water most obviously occur in coastal areas a short time after precipitation. The bloom of Exuviella occurred in the coastal area of Angola after heavy rainfall in the hills of Binnenland. The Congo and Cuanza Rivers brought much water which was spread throughout the surface layers of coastal waters." On the other hand, red tide occurs in many regions, expecially in areas of upwelling, without abnormal rainfall.

For the red tide in Florida the evidence is somewhat contradictory. Thus, the heavy red tide of 1946-47 commenced in November 1946 after a comparatively dry spell and ceased in September 1947 during very heavy rains. Because all eight recent outbreaks commenced in the fall (table 2), we have plotted the accumulated inches of rainfall for 22 south Florida weather stations for March to September, inclusive. Tabulated data were available for 51 years, from 1910 to 1960 (see app. table).

The chance for an outbreak of red tide appears to be much better in the autumn of years with heavy spring and summer rainfall than in other years (fig. 3). Only two red-tide outbreaks occurred in years with less than 40 inches. The 1916 outbreak, although apparently heavy, lasted only 2 months (October and November) and was confined to the area from Boca Grande Pass to Big Marco Pass. Likewise, the 1952 outbreak commenced in November, stopped in January, and was confined to the areas adjacent to Sanibel Island. The other outbreaks were all more widespread, occurring at various points between Tampa Bay and Cape Romano. The implication is that rainfall alone has a rather low predictive value, but, at the same time, the chances

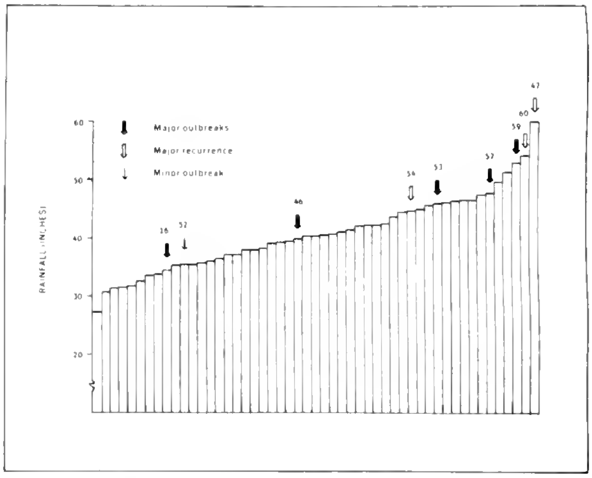

Figure 3.--Red-tide years in relation to rainfall in south Florida, March-September, 1910-60.

that an outbreak will occur are enhanced by high rainfall. Thus, high rainfall must be considered as one of the factors favoring outbreaks.

Wind

The effect of wind, or lack of wind, is often mentioned in discussion of factors favorable for blooms. Thus, the spectacular blooms of the diatom Aulacodiscus kittoni at Copalis Beach (Becking, Tolman, McMillin, Field, and Hashimoto, 1927) occur when a heavy rainstorm is followed by gentle westerly (onshore) winds. Blooms of Noctiluca miliaris on the Malabar Coast occur between monsoons during calm weather (Bhimachar and George, 1950; Hornell, 1917; Hornell and Nayudu, 1923). Blooms of Mesodinium rubrum in British Columbia occurred also during calm weather (Clemens, 1935). Lackey and Hynes (1955) commented on the effect of heavy weather in breaking up dense concentrations of G. breve.

Pomeroy, Haskin, and Ragotskie (1956) commented on blooms of Amphidinium fusiforme and Gymnodinium splendens, "All the Delaware Bay blooms occurred during periods of light winds, not exceeding Beaufort force 2 [4 to 6 knots]. On one occasion a patch disappeared when the wind rose from force 2 to 3 [7 to 10 knots]."

Light

Since most of the overblooming plankton that causes red tide is autotrophic, or depends on organisms that are, light intensity must be considered. Brongersma-Sanders (1957) stated, for instance, that plenty of sunshine seems to be another requirement for red tide. Clemens (1935) noted that the bloom of Mesodinium in British Columbia was preceded by

"A couple of weeks of bright, sunny, calm weather." Conover (1954) listed "high radiation values" as one of the essentials for a bloom of Gonyaulax. Hornell (1917) stated that red tide on the Malabar Coast required "A continuance of fine weather for a week or ten days, with plenty of sunshine."

There is evidence, however, that light is seldom a limiting factor in G. breve abundance. Wilson (1955) obtained good growth of cultures by using 175 ft.-c. (foot-candles) for 15 hours per day, and Aldrich (1960) stated that light intensity is probably not a growth-limiting factor above the 200 ft.-c. level. Aldrich (1962) established, however, that G. breve is autotrophic, requiring light for survival.

Upwelling

In many of the regions where red tides occur, nutrients are brought to the surface by upwelling of nutrient-rich waters. The nutrients do not of themselves appear to be the cause of overblooming, however. All authors seem to agree that red tides usually occur after the cessation of upwelling. For instance, Brongersma-Sanders (1948) stated that blooms of Noctiluca in Walvis Bay occur during periods of minimum upwelling; she also said (1957) that "in areas where upwelling occurs during part of the year only, red water usually develops toward the end or directly after the period of upwelling."

In regard to the situation on the west coast of Florida, Graham, Amison, and Marvin (1954) showed that the surface waters of the Gulf gradually decrease in phosphorus out to a distance of about 85 miles, and that limited upwelling of deep water at certain times had no apparent effect on the phosphorus content of water in the euphotic zone.

Nutrient Levels

It appears to be the concensus of many authors that red tides caused by dinoflagellates do not depend upon a high concentration of nutrients. In fact, dinoflagellates usually bloom after the diatoms have impoverished the water. Thus, Brongersma-Sanders (1957) said, "The greatest outbreaks of red water probably occur toward the end of a phytoplankton season. . . ." Hornel and Nayudu (1923), according to Ryther (1955), described red water caused by peridineans occurring annually along the Malabar Coast, following the cessation of the southwest monsoon, diatom blooms, and heavy rainfall. Blooms of Gymnodinium sp. occur annually along the Trivandrum Coast of India, following rains and diatom maxima, according to Menon (1945).

In summing up this reasoning, Ryther (1955) wrote that dinoflagellates have often been credited with the ability to utilize and flourish in extremely low concentrations of nitrogen and phosphorus. He stated that this concept stems largely from observations that dinoflagellate maxima, in temperate waters, follow the decline of the spring diatom flowering, and that relatively large populations often persist throughout the summer, when the supplies of these nutrients are almost undetectable.

Nümann (1957) appeared to hold similar views. He stated, "It also appears--and this is our final conclusion--that a mass outburst of phytoplankton occurs when fresh-water growth-promoting substances (trace elements, enzymes, or other biologically active substances) reach the sea. Due to the presence of a necessary quantity of nutrients in the sea, a pre-condition for the outburst of plankton in the sea exists already. Accordingly, these outbursts occur only near the coast."

In studying the phosphorus values within and without red-tide water from the work of several authors, Bein (1957) concluded concerning G. breve that, "It is possible that the threshold level of total phosphorus necessary to support dense populations of this organism is lower than originally assumed.... It seems very probable that, insofar as phosphorus is concerned, the areas of the west coast of Florida which have recorded Red Tides are, at all times, capable of supporting an outbreak...."

It also appears that G. breve does not require much nitrogen. Lackey and Hynes (1955) stated that Howard Odum failed to find any nitrate nitrogen in a series of about 15 field samples from red-tide water, taken October 6, 1953. Dragovich (1960b) stated, "No relationship was observed between the incidence of G. breve and nitrate-nitrites."

In considering the nutrients available, one must note that the rivers of the Florida west coast--especially those draining phosphatic formations--contain heavy concentrations of phosphorus (Odum, 1953; Specht, 1950; Graham et al., 1954; Dragovich and May, 1962). After weighting the discharges of seven rivers according to relative concentration of phosphorus, which differ considerably among the rivers, we estimated the metric tons of phosphorus discharged by them. The results are shown in figure 4. The Tampa Basin rivers are the Hillsborough, Alafia, Manatee, and Little Manatee; the south Florida rivers are the Peace, Myakka, and Caloosahatchee. The picture does not vary too markedly from that of rainfall. From these data one cannot assume that phosphorus necessarily had any more effect than another ingredient of river water.

Are Preceding Diatom Blooms Conducive to Red Tide?

It seems to be fairly well established that red-tide organisms can and do bloom when nutrient levels are low. There has been

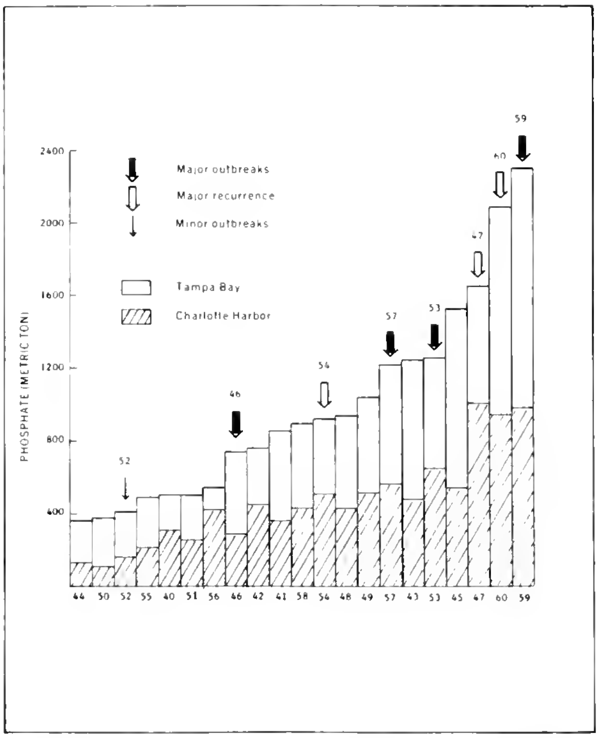

Figure 4.--Red-tide years in relation to phosphorus intrusion into Tampa Bay and Charlotte Harbor due to river discharge, March-September, 1940-60.

much discussion of the means by which the dinoflagellates concentrate the nutrients within the water column in order to bloom in relatively impoverished waters. One important question is why do they not bloom earlier in the year when nutrient levels are at their maxima.

Several authors have reasoned that the dinoflagellates may depend upon preceding organisms to concentrate the nutrients. Thus, Graham et al. (1954) stressed the ability of the dense wind-blown blooms of Skujaella to concentrate phosphorus. The theory is that when the preceding bloom dies, the phosphorus that is released will be concentrated in a small area. This theory does not explain the ability of the dinoflagellates to bloom in nutrient-poor water, nor their apparent failure to bloom earlier while nutrients are more abundant.

There appear to be two schools of thought on this subject. One idea is that the preceding blooms of diatoms may reduce one or more of the inorganic nutrients to a level favorable for dinoflagellates. The second idea suggests that the first group of organisms produces external metabolites that inhibit growth of competing organisms, but which may benefit succeeding populations (Lucas, 1947, 1949; Rice, 1954).

Distribution of Red-Tide Blooms

It is very important to an understanding of red-tide blooms to consider how concentrations of the organism are distributed in space. Despite wild statements of dense red tide over "hundreds of square miles," it is obvious from the many reports by trained observers that nothing could be much further from the truth. In fact, all but a few authors agree that red-tide blooms occur in streaks.

Reporting on an outbreak of Gonyaulax catanella in California, Bonnot and Phillips (1938) stated, ". . . It was not distributed uniformly throughout the above region but appeared in streaks and patches. It was first noted in Monterey Bay about August 11, appearing as a streak paralleling shore. This streak was about 100 yards wide and commenced approximately 200 feet offshore. Later this was scattered over a wider area, apparently by tide and wind. Other streaks and patches appeared farther offshore. . . ." Torrey (1902) gave a similar report, stating that a bloom of Gonyaulax was first noted as a red streak off the mouth of San Pedro Harbor, and adding that, "The boundaries of the red streaks were quite sharply marked, although the water between streaks often contained Gonyaulax in abundance. . . ." Whitelegge (1891) wrote that a heavy bloom of Glenodinium rubrum occurred in streaks or patches at Port Jackson, Australia.

A Delaware Bay bloom of Amphidinium fusiforme and Gymnodinium splendens was described by Pomeroy et al. (1956), ". . . the blooms were typically in the form of elongated slicks with abrupt margins. This was also true in the 1952 bloom. . . ."

Concerning the Florida red tide, Walker (1884) stated, ". . . the poisoned water was not diffused generally, but ran in streams of various sizes, as proven by fish dying in vast numbers instantly upon reaching such localities." He also quoted from fishermen who transported fish in live wells in their vessels, "The poisoned water runs in streaks, for often when three or four smacks are in company one or two will lose all their fish in a few minutes, while the others, a short distance off, lose none." Describing the 1916 outbreak, Taylor (1917b) said, ". . . This colored water was described as being not uniformly distributed, but occurring in streaks, and it was in these streaks that the fish are said to have perished. . . ."

Finucane (1964) stated, ". . . Since its incidence during nonbloom periods is primarily confined to offshore waters, the organism probably is more neritic than estuarine. G. breve occurred in approximately equal frequency in both estuarine and neritic waters only during the red-tide outbreaks in 1954 and 1957. . . ."

Gunter (1952) reported, "In the summer of 1935 a very heavy mortality of marine fishes and other animals occurred in the Gulf of Mexico and extended for a distance of 250 miles from the Rio Grande northward. A few fishes were killed in the lower bays but practically all of the mortality was confined to the Gulf. . . ." In a later outbreak in this area, Wilson and Ray (1956) identified the causative organism as Gymnodinium breve.

Semicircular surface structures were reported by Ingle, Hutton, Shafer, and Goss (1959) to be common features of the 1957 red-tide outbreak near the mouths of passes. They said: "In every case observed by the authors (R.M.I. and R.F.H.) the discolored water, denoting a high concentration of dinoflagellates, was found from the interface and extending seaward." Ingle also stated (USFWS, 1958), "We made one trip along interphase and found high concentrations as far as 15 miles offshore. Very high counts as far as we could go."

Slobodkin (1953) based his hypothesis of stable water masses wholly on theory. His theory that organisms develop in a "discrete mass of water of relatively low salinity" differs from observations on blooms occurring in streaks, the abrupt margins of the blooms, and the formation of blooms at interfaces. The theory does not explain how the organisms, floating in their lens of water, concentrate high amounts of nutrients from nutrient-poor water.

Effect of Dead Fishes in Continuing a Red-Tide Bloom

The question of whether or not fish killed by red tide aid in perpetuating or spreading red tide is of some importance. Proponents of such an hypothesis point out the immense quantity of nutrients that can be made available by the decaying carcasses.

Collier (1955) squeezed juices from freshly killed fish into a culture he described as about 3 million organisms per quart; overnight they tripled in number. Wilson (1955) discovered, however, that if fish autolysate is added to the original culture medium, bacterial growth frequently is stimulated, and the culture dies. For instance, when added to a culture of 3 1/2 million per liter, the organisms increased in 4 days to 9 1/2 million but then fell to zero in 1 week.

In considering these results, it should be noted that when fish are killed by red tide, the fresh juices are not squeezed into the water; the fish undergo a process of putrefaction during which the bacteria must increase enormously. In this regard Ray and Wilson (1957) mentioned the effect of bacteria in reducing the toxicity of G. breve cultures, and also mentioned the experiments of Shilo and Aschner (1953) in which bacteria acted as a detoxicating agent in cultures of Prymnesium parvum.

Since Aldrich (1962) has established that G. breve is autotrophic, it would seem that there would necessarily be some delay before the constituents of whole fish had had time to recycle inorganic nutrients into the water.

It should be noted that during the period of time necessary for putrefaction, surface-drifting fish may be blown far offshore, or onto some beach, many miles from the red water which killed them. Hela (1955) showed that the drift of the dead fish can for practical purposes be determined by wind observations alone. Speaking of the 1947 outbreak, Anderson (USFWS, 1958) said, ". . . in that summer some of the fish were pushed out, but that doesn't mean that you don't have offshore kills. The big concentrations were inshore. Fish that were far offshore were in clear water. Most fish found offshore were in a bad state of decay, which made me think they had been drifting for a long time after being killed in red water." Wilson (USFWS, 1958), when questioned, answered that in general fish kills occur close to shore, except in certain instances, and that he did not know of a bloom completely offshore, not associated with an inshore bloom. In November 1954 during a period of strong northeast winds, the Oregon found dead fish 50 miles offshore. Finucane (USFWS, 1958) said, ". . . In 1947 I don't think they died near the Keys but were moved down by wind action."

FIELD OBSERVATIONS ON FLORIDA RED TIDE

To aid in guiding our thinking, we compiled table 1, showing the occurrence of recorded outbreaks of red tide during the 117 years from 1844 to 1960. We found records of 20 toxic red tides, 3 in Texas and 17 on the west coast of Florida, all of which can reasonably be attributed to blooms of Gymnodinium breve. In evaluating these records, it should be borne in mind that, especially in the earlier reports, the observers did not separate cause and effect. Reports of great quantities of fish drifting ashore at Key West or on the Dry Tortugas for instance, gave no indication of the area or areas in which they were killed.

Some of the recorded outbreaks may have been minor. For instance, concerning the 1952 outbreak, Lackey and Hynes (1955) wrote, "The 1952 outbreak was apparently rather limited in the area affected, which seemed to center around Sanibel Island. There is little published information on this outbreak, at least at the present time." Both Collier (1954) and Chew (1953) confirmed the occurrence of this outbreak, however, placing it around the Sanibel Island area in November.

Table 1.--Occurrences of Florida red tide, 1844 to 1960

No.	Year	General area	Initial month	Final month	Months unknown
1...	1844.......	....	? (1)......	? (1)....	(1)
2...	1854.......	....	? (1)......	? (1)....	(1)
3...	1856 or '57	....	? (2)......	? (2)....	(2)
4...	1865.......	....	? (3)......	? (3)....	(3)
5...	1878.......	Tampa to Dry Tortugas..........	Sept. (2)......	Oct. (2)....	(1,5)
				Nov. (3,4)..	....
6...	1879.......	....	?...........	?..........	(1)
7...	1880.......	Tampa to Key West.............	Aug. (1)......	Dec. (1)....	(3)
		Egmont Key.....................	Oct. (6)......	?..........	....
8...	1882.......	Clearwater to Egmont Key.......	July (7)......	?..........	....
9...	1883.......	....	?...........	....	(8,9)
	1884.......	....	....	?..........	....
10...	1885.......	Egmont Key to Charlotte Harbor.	Oct. (10).....	?..........	(11)
11...	1908.......	....	?...........	?..........	(8)
12...	1916.......	Boca Grande to Big Marco Pass..	Oct. (8)......	Nov. (8)....	....
13...	1935.......	South Texas....................	June (12,13)...	Aug. (12,13).	(14)
14...	1946.......	Boca Grande and South..........	Nov. (15).....	....	....
	1947.......	....	....	Jan. (9,15)..	....
	1947.......	Reached Tampa Bay in July......	Mar. (15,16)...	Sept. (17)...	....
15...	1948.......	South Texas....................	Fall (14).....	....	....
16...	1952.......	Near Sanibel...................	Nov. (18,19)...	....	....
	1953.......	....	....	Jan.(17,18,19)	....
17...	1953.......	Tampa and South................	Sept. (18,19)	....	....
	1954.......	....	....	Mar. (20)...	....
	1954.......	Venice and South..............	July (21).....	....	....
	1955.......	....	....	Feb. (21)...	....
18...	1955.......	South Texas....................	Sept. (22).....	Sept. (22)...	....
19...	1957.......	Tampa and south................	Sept. (21).....	Dec. (21)...	....
20...	1959.......	Tampa to Venice................	Sept. (23).....	Nov. (23)...	....
	1960.......	Egmont Key.....................	Mar. (23).....	Mar. (23)...	....
	1960.......	Egmont Key.....................	July (24).....	Aug. (24)...	....

[1] Ingersoll, 1882
[2] Jefferson et al., 1879
[3] Glazier, 1882
[4] Jefferson, 1879
[5] Moore, 1882
[6] Walker, 1884
[7] Anon., 1883
[8] Taylor, 1917
[9] Gunter, 1947
[10] Glennan, 1887
[11] Canova, 1885
[12] Lund, 1935
[13] Burr, 1945
[14] Gunter, 1952
[15] Gunter et al., 1948
[16] Galtsoff, 1948
[17] Univ. Miami, Mar. Lab., 1954
[18] Collier, 1954
[19] Chew, 1953
[20] Lackey and Hynes, 1955
[21] Finucane, 1964
[22] Wilson and Ray, 1956
[23] Finucane, 1960
[24] Finucane, 1961

Seasonal Occurrence of Red Tide

Table 2 (from data of table 1) shows the seasonal occurrence of red tides in Florida for the eight outbreaks for which the data appear to be reasonably accurate as to month. Several features are of interest. All outbreaks commenced between August and November, and half started in September. Six of the outbreaks ended between November and February, suggesting the effect of lowered temperature in controlling growth of the organism. At least three of the outbreaks apparently did not cease during winter and spring, but merely continued at a slow pace until more temperate weather returned.

Another interesting feature of table 2 is that of 48 months in which toxic blooms were present, only 11 occurred during the 6-month period from February through July. This coincides with the observations and opinions of several authors that most dinoflagellates bloom after the diatom flowering and after the nutrients have become relatively scarce. It also coincides with the data on temperature, mentioned previously, which indicate that *G. breve* can thrive at temperatures from 16° to 27° C. This seasonal blooming in early autumn, however, could also be encouraged by seasonal rainfall, which is normally much higher in June, July, August, and September than in other months.

The Role of Convergences in Causing Red-Tide Blooms

Several cogent arguments support the hypothesis that convergences play an important role in initiating and maintaining toxic concentrations of the Florida red tide. Some of these arguments are:

1. The Florida red tide apparently can aggregate in fish-killing concentrations at a very low nutrient level; however, the phosphorus values within such concentrations (including the organisms in the samples) are often high--often far too high to be accounted for without supposing the organisms to be capable of concentrating practically all of the phosphorus available in the water column.

Table 2.--Seasonal occurrence of Florida red tides

Year	Months[1]												Duration	
	J	F	M	A	M	J	J	A	S	O	N	D	Sum	Intense
1878									$\underline{X}$	X	X		3	3
1880								$\underline{X}$	X	X	X	X	5	5
1916										$\underline{X}$	X		2	2
1946											$\underline{X}$	X		
1947	X	-	X	X	X	X	X	X	X				11	10
1952											$\underline{X}$	X		
1953	X												3	3
1953									$\underline{X}$	X	X	X		
1954	X	X	X	-	-	-	X	X	X	X	X	X		
1955	X	X											18	15
1957									$\underline{X}$	X	X	X	4	4
1959									$\underline{X}$	X	X	-		
1960	-	-	X	-	-	-	X	X					12	6
Initial months								1	4	1	2			
Terminal months	1	1						1	1		2	2		
Months of intensity	4	2	3	1	1	1	3	4	7	7	9	6		

[1] Underlining indicates initial month of an outbreak; dashes join portions of same outbreak during temporary recession.

To accomplish this concentration, either the organism must travel through the water column, or the water column must move past the organism.

2. The occurrence of blooms in streaks with abrupt margins suggests that the organisms are concentrated by one or all of three means:

a. Convergences paralleling the shore, set up by gentle onshore winds.

b. Convection cells parallel to steady winds, causing parallel streaks.

c. Convergences at the mouths of passes, where the residual outward flow of less saline water near the surface meets the more saline Gulf water.

3. The repetition of outbreaks adjacent to the mouths of passes where convergences would occur most frequently and consistently.

4. The fact that (unlike diatoms) dinoflagellates can resist vertical currents. Peters (1929) suggested that some species can successfully oppose a vertical current of about 1 cm. per second; he said that *Ceratium* can move through 5 to 10 m. in 12 hours or less. Pomeroy et al. (1956) found that *Gymnodinium* sp. would seek a light source at 0.3 to 0.8 cm. per second.

5. The sudden appearances of fish-killing concentrations of *G. breve* in areas in which continuous sampling showed densities far too low to reach the high concentrations found, in the allotted time, if the increase were based on division rates. Thus, Finucane (USFWS, 1958), speaking of the beginning of the 1957 outbreak, said, "The population did not build up rapidly at the time of the last outbreak, only to 12,500 per liter a day and a half before fish kills started." On the question of division rates Wilson (USFWS, 1958) stated, "It fluctuates, the average rate of a division is 0.4 per day for a particular day but not over a longer period." Lackey and Hynes (1955) stated that under optimum conditions several divisions may occur in 24 hours. Collier (1955) wrote that the addition of juices from freshly killed fish caused an "explosive bloom" which tripled the number overnight. Wilson (1955), however, using the same means, found it took 4 days to triple the numbers in the culture.

6. Strong winds usually break up fish-killing concentrations suggesting that winds of much velocity cause stronger downward vertical currents than can be opposed by the organisms and cause them to become dispersed through the water in concentrations below the lethal level. Wilson (USFWS, 1958) stated that, ". . . Strong offshore winds, roughly above 18 mph, will probably be detrimental to a bloom developing but calm to moderate onshore wind will probably be beneficial."

7. When severe outbreaks are dispersed by strong winds, apparently enough organisms remain to cause outbreaks to recur quickly when the wind moderates. Such sudden recurrences imply the existence of a concentrating mechanism.

8. Despite strong tidal movements through the passes, and a general residual current flowing northward along the coast, a fish-killing concentration may remain in virtually the same place over several days at a time. This persistence could be explained by the organisms being held in one area by a convergence at the mouth of the pass. Wilson (USFWS, 1958), in discussing an early control experiment, said, ". . .this bloom had persisted in this area [0.2 square mile] for 22 days." He also stated, "If you find a high concentration of organisms one day, it tends to be at this location the next day. If there is water movement you would expect to find them at some other location and not at approximately the same position day after day."

There is some evidence that dinoflagellates tend to sink toward the bottom at night and rise to the surface during the day. The sinking may not be purposeful movement, but merely a tendency for the organisms to become dispersed at night when there is no light to bring them toward the surface. Pomeroy et al. (1956) mentioned that they observed a bloom of Gymnodinium sp. that for 4 successive days disappeared at night and in the early morning and reappeared each day at about 9 a.m. While spraying copper sulphate during the control experiment in the heavy outbreak of 1957, it was noted that concentrations of G. breve were not apparent in the early morning before the sun attained a high angle.

Because dinoflagellates can move vertically they may be able in calm weather when convergences are fewer to strain the nutrients from a goodly part of the water column.

That a dense concentration of organisms is usually formed either at a convergence or in very calm water is shown by the fact that concentrations of G. breve often occur in places protected from currents, such as small bays, or the stagnant fingers made by dredging narrow blind channels to make waterfront lots (Ingle et al., 1959). Wilson (USFWS, 1958) said, "You normally have more plankton bloom and red tide during periods of calm weather."

Coastwise and Seasonal Abundance

One of the first steps in analyzing the 1954-60 raw data on G. breve was to determine how the organisms were distributed both seasonally and in relation to the coast. For this purpose the data were coded into 10 north-to-south areas, each measuring 25 miles along the general trend of the coast (fig. 1). To obtain the distribution in relation to the land, the data were also coded in bands of distance offshore, and, for stations inside the fringing barrier islands, by distance to the mouth of the nearest pass. It was obvious that in 1954-60 organisms were never very abundant from March through August. For the 3-month period from September through November, the contour lines of relative abundance are shown in figures 5 and 6. Centers of high abundance were in the Sanibel Island area and adjacent to the mouth of Tampa Bay. Heavy concentrations tended to hug the coastline. A light concentration extending seaward off Tampa Bay may be a reflection of the permanent counterclockwise eddy which, according to Hela, de Sylva, and Carpenter (1955), seems to have its northern end at the latitude of Tampa Bay.

During 2 months (December-January) the distribution was in general similar (figs. 7 and 8), but the level of abundance had fallen in the north, which may well reflect the curbing effect of cooler water.

Pollution as a Contribution to Red-Tide Outbreaks

The question has been raised as to whether nutrient-rich pollution, especially domestic sewage, contributes in initiating or maintaining outbreaks of red tide. Odum (1953) found in Florida that 18 small unpolluted streams contained 0.019 p.p.m. (parts per million) of phosphorus, 10 small acid streams draining phosphatic formations contained 0.413 p.p.m., and 7 streams not draining phosphatic formations but receiving sewage contained 0.836 p.p.m. The effects of sewage could result from an increase in phosphorus and nitrogen or from some other condition. Bacteria working on sewage, for instance, might increase the amount of Vitamin B_{12} available. Wilson (USFWS, 1958) said ". . . possibly the most important aspect of stream discharges which are contributing to red tides is that some form of chelating agent may be in this water. . . ."

If red tides are tending to occur more frequently, and especially if they are tending to occur more toward the northern portion of the red tide area, one might well suspect that pollution from the mushrooming cities around Tampa Bay is contributing to their occurrence.

LIFE FORMS OF GYMNODINIUM BREVE

Very little has been published on life forms of G. breve. Detailed descriptions of the organism appear in Davis (1948) and Lackey and Hynes (1955). The latter stated that the only observed method of reproduction is by binary fission. Wilson (USFWS, 1958) mentioned observations on cysts. He stated that he could not make G. breve encyst by temperature adjustments. When questioned concerning whether cysts would divide, he stated, "I have put in from one to 20 in sterile media and found that they will encyst and divide." He

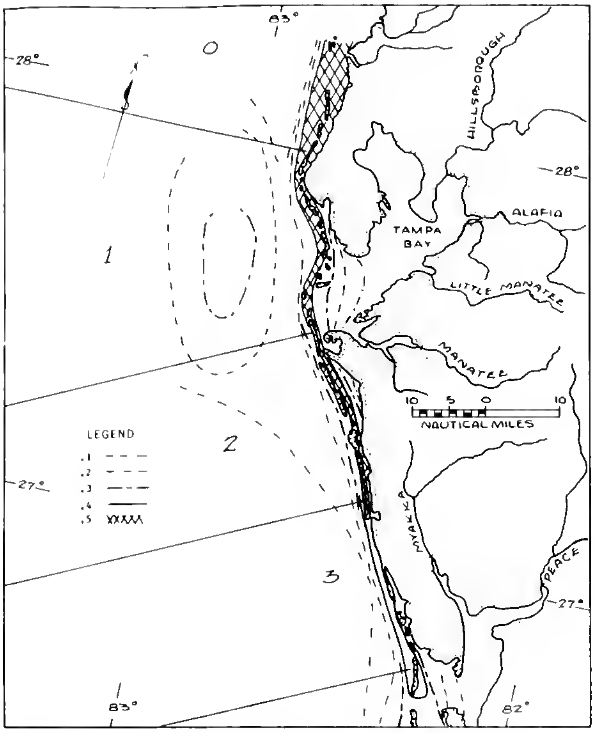

Figure 5.--Contour lines showing relative density (geometric mean of number per ml.) of Gymnodinium breve in North-South areas 0-3, September-November, 1954-60.

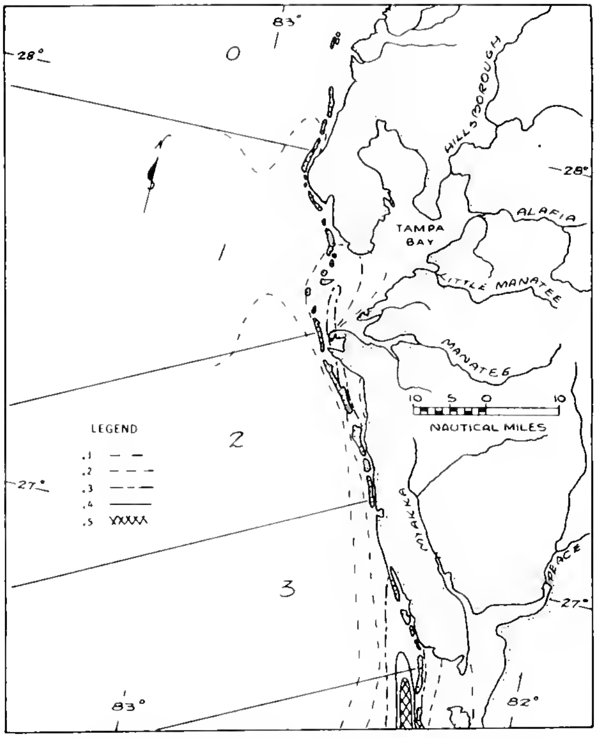

Figure 7.--Contour lines showing relative density (geometric mean of number per ml.) of Gymnodinium breve in North-South areas 0-3, December-February, 1954-60.

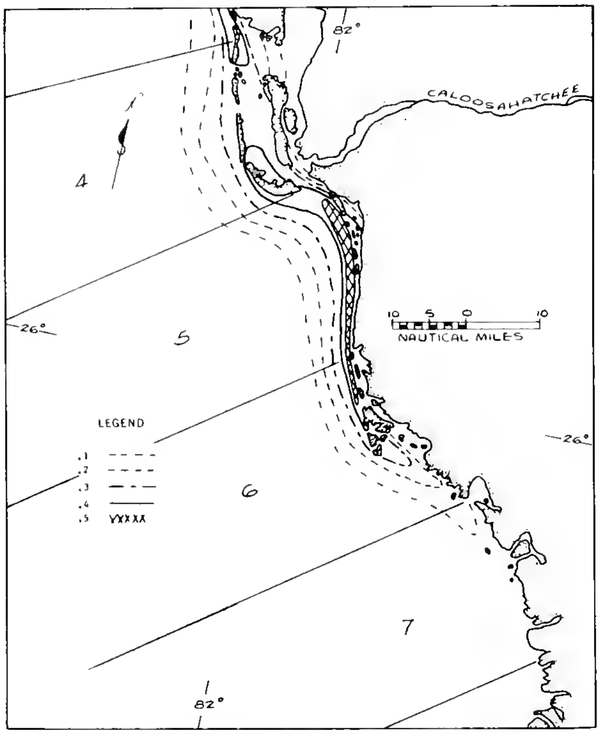

Figure 6.--Contour lines showing relative density (geometric mean of number per ml.) of Gymnodinium breve in North-South areas 4-7, September-November, 1954-60.

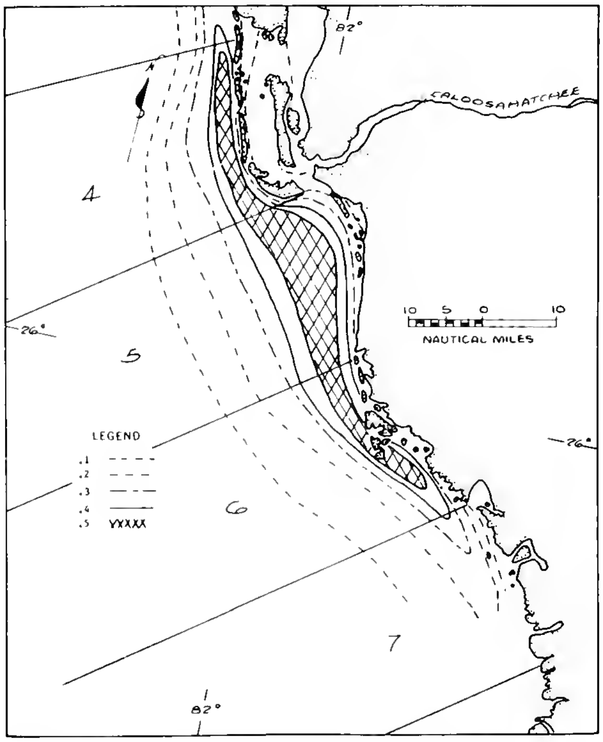

Figure 8.--Contour lines showing relative density (geometric mean of number per ml.) of Gymnodinium breve in North-South areas 4-7, December-February, 1954-60.

also stated, ". . . Cysts form chains and when culture is stirred these tend to remain together, but I have never seen a chain formation of normal free swimming cells."

There are several statements that G. breve affects the viscosity of the water when numerous. Galtsoff (1948) stated, ". . . the water had an oily appearance. When dipped up and allowed to stand for 5 to 10 minutes, it became thick, sometimes almost of a consistency of Karo syrup, and slimy to the touch. . . ." Gunter, Smith, and Williams (1947) reported, "The water was viscid and slimy, having the consistency of diluted syrup." Collier (USFWS, 1958) said, ". . . observing with a dissecting microscope, the viscosity seemed to be caused by the organisms agglutinating. While I watched they started joining in long chains, long branching chains. . . ."

There may be another answer to the high viscosity. Martin and Nelson (1929) found by killing Gymnodinium sp. with special solutions that they could observe a gelatinous envelope as thick as the diameter of the cell itself. They stated, "Gelatinous envelopes are common among dinoflagellates when encysted, but not when active. The cells referred to in this connection were actively motile. A similar envelope has been noted occasionally surrounding other species of naked dinoflagellates in the active condition, but only when killed by the iodine or bichloride methods. In red water plankton in which Amphidinium fusiforme is the dominant species, the Amphidinium cells tend to cling together in clumps, but no gelatinous envelopes can be demonstrated. In many of the clumps (although not in all), however, they may be seen to be clustered thickly about a cell of the Gymnodinium. This gelatinous envelope may well be a factor of importance in holding the organisms together, once they are massed by a favorable combination of light, water temperature, and tidal currents."

Conjugation of G. breve was discussed by Wilson (USFWS, 1958). He said, "In the condition I have called conjugation I have never seen more than 2 organisms attached together. You may find them in various positions, but there is always a stalk-like process between two individuals."

The size of G. breve is usually given as between 20 and 30μ. Wilson (USFWS, 1958) said, ". . . In certain cases in the field you will see a fairly large form which appears to have no chromatin material at all. . . ."

CONTROL OF RED TIDE

It is difficult to discuss control of red tide without first discussing the type and scope of the damage inflicted. This damage has three main aspects, 1) effect of red tide on the tourist business, 2) effect on the sport and commercial fisheries, and 3) effect on public health.

Damage from Red-tide Outbreaks

Since red-tide outbreaks usually start in the fall, just as the tourists are commencing to move south, an outbreak can cause very serious losses, especially at seaside communities in which the accommodation of tourists is often the chief, or sometimes the only, major business. Rotting fish on the beaches, and sometimes acrid aerosols containing toxin, will drive tourists away. From this standpoint alone, control is highly desirable.

The effect on the fish populations has not been nearly as severe as the layman imagines when he hears of the death of millions of small fishes. The percentage kill is doubtless low. For instance, Lackey and Hynes (1955) stated, ". . . the last localized outbreaks of the 1953-54 Red Tide are only a few weeks past, yet sports fishing (grouper, speckled trout, mackerel, and redfish) has been generally good throughout the entire area. . . ."

The kill of fishes by the 1946-47 red tide was estimated by Gunter, Williams, Davis, and Smith (1948) as 500 million fish. This figure may sound large, but actually it is not. If we realize that these fish will probably run no less than 10 to the pound, the total is only 50 million pounds. Every year about 1 billion pounds of menhaden are caught along a 300-mile stretch of the northern Gulf, but this enormous catch of a single species does not appear to be harming the supply.

The effect of red tide on public health is rather debatable. For a short while during severe outbreaks there will be aerosols from breaking surf when the wind is blowing onshore. Long exposure close to, or on, the beach can be very irritating to the respiratory tract. A few people are so adversely affected that they must leave until the outbreak is over. More serious have been the questions regarding the safety of seafood products, shellfish in particular, during an outbreak; however, the Gulf Coast Shellfish Sanitation Research Center (1964) stated that, ". . . rigorous proof of the Red Tide organism as the cause of shellfish toxicity remains to be demonstrated." Since Gonyaulax and other dinoflagellates occur, often in fair abundance, in the red-tide area of the coast, it seems hardly fair even to attempt to indict G. breve without very definite proof. Oysters tend to occur, except when transplanted, in areas with salinities below those tolerated by G. breve (which is neritic), but well tolerated by several species of estuarine dinoflagellates.

Methods of Control

Methods of control of red tide depend largely on whether the objective is prevention, control, or mere alleviation.

Under alleviation fall such measures as seining of dead fish to keep them off the beaches; also, the common practice of using bulldozers and other power equipment to bury mechanically, or to gather together and remove, the dead fish washed or blown ashore. At best these are temporizing measures. As we have noted previously, fish-killing concentrations of red tide tend to remain close to shore, sometimes inside the passes. These temporizing measures do not help against the irritating aerosols, nor can they keep all fish off the beaches when the concentrations impinge so closely on the fringing islands. Numerous suggestions have been made for both prevention and control, each of which we discuss in turn.

Prevention of Outbreaks

Prevention of outbreaks before they get started involves alteration of the habitat either chemically or physically.

1. Inhibiting the growth of *G. breve* by raising and maintaining the concentration of heavy metals at an inhibitory level. The idea here was to raise the level of copper (or other heavy metal) in the inshore waters sufficiently high to inhibit the growth of the red-tide organism without actually destroying it. Should an outbreak nevertheless occur, only minimal amounts of copper added to the water should suffice to kill *G. breve* because of the existing high level of copper. The feasibility of this idea was tested by using copper ore, and the method was rejected (see Marvin 1958, 1959; Marvin, Lansford, and Wheeler, 1961).

2. Keeping the nutrient level low by curbing use of streams and bays for disposal of nutrient-rich sewage or other pollutants. Since *G. breve* can apparently thrive in nutrient-poor water, this suggestion does not appear too promising. We do need to know whether sewage pollution contributes other substances needed by the organism.

3. Controlling river flows in streams for which water can be stored so as not to create ideal conditions for blooming. Some streams, particularly the Caloosahatchee River, have enormous storage capacity. By regulation of the flow (a detailed hydrographic study at all flow levels is highly desirable) it may be possible to prevent the formation of water of suitable salinity in a zone of strong convergences. Seasonal releases of blocks of water, either to get rid of surplus water during a period when conditions appear unsuitable for blooms, or to suddenly lower the inshore salinity below tolerable levels for *G. breve* should be considered. One might speculate as to whether the former larger flows of fresh water southward through the Everglades had any effect on earlier red tides, which seem to have been more southerly in occurrence.

4. Encouragement of competing or inhibitory organisms by special types of fertilization. This idea appears to be implicit in the suggestion of the University of Miami Marine Laboratory (1954) that the carrying out of extensive fish culture in the back bays might cause changes in the habitat detrimental to *G. breve*. The danger here lies in losing the estuarine nursery areas needed by shrimp and various sport and commercial fishes.

5. Altering the physical habitat through construction of underwater barriers, jetties, or similar structures at passes to restrict mixing of Gulf and bay waters, and perhaps to change the pattern of the convergences at the mouths of the passes. This suggestion (which we have slightly elaborated) was made by Robert Hutton at the meeting of the Advisory Committee at the 1958 symposium (USFWS, 1958). It certainly deserves full attention.

Control of Outbreaks

Only a few of either the preventive measures listed above or the control measures discussed below have been tried, even on a laboratory scale. Nevertheless, at the present state of our knowledge, we cannot afford to dismiss or reject ideas in cavalier fashion. Some of the untried suggestions undoubtedly have merit--it is a question of patient research, pilot experiments, and economics.

1. Biological control through the use of bacteria. The use of bacteria to destroy the toxin of the red tide was suggested at the 1958 symposium (USFWS, 1958). The use of bacteria that destroy vitamin B_{12} was suggested by Hutner and McLaughlin (1958), but dismissed with the comment that "truly enormous quantities of bacteria would be required. . . ."

2. Biological control through encouragement of predator organisms. The encouragement of predator organisms was mentioned by several authors. Galtsoff (1948) mentioned the ingestion of *G. breve* by a cladoceran, *Evadne*. Hutner and McLaughlin (1958) mentioned the ciliate protozoans and the luminous dinoflagellate, *Noctiluca*. Torrey (1902) mentioned the appearance of *Noctiluca* in great numbers toward the end of July and their devouring *Gonyaulax* "with avidity." There is no comment on how to encourage these predators, short of providing them a red-tide bloom.

3. Physical control by high-frequency waves. Little attention has been paid to physical means of control. Lackey and Hynes (1955) stated, ". . . It has already been shown, however, that there is no useful killing action in a high-frequency radio field. . . ."

4. Control by changing the pH. Galtsoff (1948) wrote ". . . The use of powdered calcium oxide (unslackened lime) suggests itself, for its addition to sea water will raise the pH to a level which is beyond the tolerance of the dinoflagellate. . . ." [p. 35.] Wilson (1955) said that G. breve grows best in pH of 7.3 to 8.1, but survives pH from 7.0 to 8.6. Aldrich (1959) gave 7.5 to 8.3 as the pH range for good growth of G. breve and said that a pH below 7.3 was definitely toxic.

5. Control by adsorption of vitamins or chelators or both. Adsorption of vitamins required by G. breve through large-scale dusting with charcoal was suggested by Odum, Lackey, Hynes, and Marshall (1955) as a means of modifying offshore blooms. This suggestion should be tested in the laboratory.

6. Destruction of G. breve by nonselective chemicals. The most widely tried method of control for red tides has been the spreading or dusting of water areas with nonselective chemicals. The question of what destruction these chemicals can do to organisms other than the one in bloom is usually based on general uneasiness, without substantial proof. For instance, few question the spraying of valuable estuarine nursery grounds with practically nondestructible hydrocarbons in the name of mosquito control, yet many worry about a very low concentration of copper sulfate, which has only a momentary effect.

Several nonselective chemicals have been suggested for killing red-tide organisms directly:

Ammonia was sharply inhibitory to growth of Prymnesium parvum; it was less toxic at high salinity or at low pH (McLaughlin, 1958).

Ferric chloride and chlorine gas were used in Japan; materials were discharged over the stern of a boat so they could be churned into the water by the propeller (Anon., 1934).

Calcium hypochlorite or liquid chlorine was used by the Japanese either after or with copper sulfate to prevent the growth of bacteria after killing the dinoflagellates (Galtsoff, 1948).

Copper sulfate is the most widely used chemical. The Japanese have used it for many years to protect their oyster beds from red tide. It was tried on a small scale in Florida in 1952 by discharging a concentrated solution of 3,000 pounds of copper sulfate from the ballast tanks of the Alaska. In 1953 sacks of copper sulphate were towed from small boats off Anna Maria Key. Later a small area was dusted by plane. None of these experiments was on a sufficiently large scale to indicate the effectiveness of copper sulfate.

In a large-scale experiment, during the heavy outbreak of 1957, 105 tons of copper sulfate were spread by crop-dusting planes at about 20 pounds to the acre along 32 miles of beach between Pass-a-Grille and Anclote Keys (Rounsefell and Evans, 1958).

7. Destruction of G. breve by selective chemicals. The primary objective is to discover a chemical or chemicals toxic to G. breve at low enough concentrations to hold promise of being cheap enough to use for control, that at the same time is specific for G. breve or perhaps closely related species. The screening of 4,306 compounds, including most of those screened in past years in developing a specific larvicide for the sea lamprey (Petromyzon marinus) in the Great Lakes, yielded 55 compounds toxic at 0.01 p.p.m. (Marvin and Proctor, 1964). Further tests (unpublished) have shown that several of these highly toxic compounds do not harm several other estuarine organisms. The laboratory testing of these very toxic compounds, when completed, should lead to pilot experiments under field conditions.

SUGGESTIONS FOR FUTURE RESEARCH

In summarizing research to date on red tide, we are immediately aware of the fact that, despite some very significant progress, many gaps remain in our knowledge. When we consider the tremendous expenditures of time and effort that have gone into the solution of many medical problems, such gaps are not surprising. Serious red-tide research is comparatively recent; barely 10 years have elapsed since the first successful culturing of the causative organism. Perhaps the chief deterrent to progress has been the fluctuation in financial support. Heaviest support has followed severe outbreaks; support has declined between outbreaks until, at times, the level has become too low to provide adequate continuity of field data. Despite the marked improvement in the field programs since the 1958 symposium finances have been insufficient to keep up continuity in field and laboratory and at the same time carry out research on some of the imaginative suggestions that were made. Perhaps some reorientation may aid in stretching the research dollar.

Several items suggested by the Advisory Committee at the 1958 symposium have been worked on, and some completed. These items follow:

1. Testing chemical compounds to discover one or more specific for G. breve. This work has resulted in a report by Marvin and Proctor (1964) for 4,306 chemicals, several of which show promise. This item should be pushed vigorously.

2. Does G. breve require a heterotrophic existence? Aldrich (1962) showed that G. breve

is photoautotrophic, requiring both light and CO_2 for growth and survival.

3. Would a copper ore dike maintain a high enough level of copper in the water to inhibit growth of G. breve? The answer is no (Marvin, Lansford, and Wheeler, 1961).

The Advisory Committee urged the Bureau of Commercial Fisheries to attempt to publish both the data and the results of its red-tide investigations. Since 1958 the Bureau has published all its raw field data and a number of reports on both field and laboratory projects.

Laboratory Studies of the Organism

Laboratory studies of both unialgal and bacteria-free cultures have yielded considerable information on the physiology of G. breve.

More work is needed, however, especially on the role of other plankton organisms in promoting or inhibiting growth. This type of work may involve the use of radioisotopes to trace the flow of nutrients.

There has been much discussion of the possible role of chelators in stream water or surface runoff in promoting growth.

In both of the above cases it is possible that experiments have been hampered by the very high surface:volume ratio of the test tubes in which most experiments have been carried out. In 1958 several advisers suggested that cultures be grown in large tanks to answer better such questions as killing concentrations of G. breve and the effect of dead fish, either in perpetuating a bloom, or possibly in creating lethal concentrations of bacteria.

Some have advocated attempting to cause a bloom of red tide by such measures as dumping a barge of dead fish, dumping large amounts of pollutants from selected localities, or by fertilizing an area containing organisms with specific nutrients. Most agreed that to gain sufficient control over the experiments, the studies might better be performed in large tanks. Discovering how to create a bloom is the opposite approach from observing blooms in the field and then trying to decide the cause. We believe the problem should be approached from both directions. In any such tank experiments, we believe that an attempt should be made to imitate natural conditions insofar as practicable. Thus, a very large tank might offer a fine opportunity to test the role of convergences in concentrating the organisms, and perhaps to solve their ability to grow in water of low nutrient content.

The life forms of G. breve have been observed, but work is needed to determine the factors causing encystment, the conditions under which cysts can survive, the length of time they can survive, and the conditions favoring resumption of the normal form. The winter survival of G. breve in the deeper (and warmer) offshore waters (as deep as 123 feet) has been stressed (Dragovich, 1960b; Dragovich and May, 1961; Finucane, 1960), but overwinter survival of encysted forms in the shallower inshore waters is a distinct possibility that requires investigation. Should this inshore survival occur it might be remotely possible, following heavy red-tide outbreaks in the fall, to modify the sudden recurrences in the spring (as happened in 1947, 1954, and 1960) by destruction of the cysts on the bottom.

Binary fission was the only method of reproduction observed by Lackey and Hynes (1955). Conjugation was also observed by Wilson (USFWS, 1958). Because it is apparently not often observed, the discovery of what favors conjugation and its role in maintaining population abundance might be important.

Although the red-tide organism normally measures about 20 to 35 μ, large forms, perhaps up to 80 μ, have been observed. Wilson (USFWS, 1958) mentioned that occasionally in the field one observes ". . . a fairly large form which appears to have no chromatin material at all. . . ." He did not observe these in the laboratory. It would be of interest--perhaps of some importance--to discover whether this large form is a special life form of G. breve or perhaps a distinct species.

Opinions seem to differ as to whether G. breve can form chains. Wilson (USFWS, 1958) said that cysts form chains, and that when the culture is stirred these tend to remain together, but he had never seen a chain formation of normal free-swimming cells. Collier (USFWS, 1958), however, mentioned watching the organisms form long chains. His observation was apparently made while he was watching a very high natural concentration--probably much higher than any encountered in the laboratory. It is possible that dense concentrations may cause the organisms to act in a different manner. The possibility that a difference in life forms or manner of reproduction may be triggered by excessively high concentrations deserves investigation.

There appears to be some question whether changes in color of red-tide water are caused by density of the organisms, by the angle of the light, or by the age of the population. Wilson (USFWS, 1958) said that each culture seems to have a tendency to accumulate oil droplets with age, which will give a different color comprehension. If either color or oil accumulation could be used as a gross measure of population age, it might be useful in determining whether a population is increasing or declining.

Field Studies of Red Tide

Since 1954 the Bureau of Commercial Fisheries has gathered environmental data that included concurrent enumerations of G. breve. One of the chief aims when this sampling began was to attempt to predict red-tide outbreaks by noting the gradual increase in abundance of the organisms. Unfortunately, high concentrations of the organism appear with little prior warning. In 1957 this program was revised to give much more intensive coverage of one area--Tampa Bay and vicinity. More chemical determinations were also added.

One of the first tasks should be to complete the analysis of this accumulation of environmental data. It is important to know which factors can safely be dropped, which must be retained, and how much sampling is needed for a reliable estimate of population changes. In the analysis of these data we feel it important to obtain detailed data on wind direction and velocity. If convergences play as important a role as is strongly suspected in the rapid concentration of organisms, and possibly equally important, in permitting the organisms to grow in low-nutrient water, then winds may be one of the major factors in overblooming. Any modifications of the present sampling program should await the results of the analysis of the accumulated data to prevent discontinuity of the records.

A detailed hydrographic survey of the areas adjacent to the mouths of the principal passes should be made under varying conditions of tide, wind, and residual outflow of brackish water. This survey should include an attempt to locate the position of convergences and the speed of the vertical currents. Once this detailed information is available for a major pass we suggest a model study to determine whether it is feasible to make any modifications of the pass (such as underwater barriers to restrict mixing, jetties, etc.) to aid in two objectives: 1) to lessen the formation of convergences and 2) to prevent the formation of large bodies of mixed Gulf and bay waters of salinities favorable for G. breve.

One important aspect of the field work that may need more emphasis is obtaining reliable quantitative data on the relative abundance, both seasonally and annually, of other plankters. G. breve can grow in water of relatively high salinity but appears to bloom more often in the fall, usually at lower salinities--suggesting that the stimulation of growth depends upon some terrigenous substance brought into the Gulf by the rivers, or upon previous changes in the neritic waters dependent upon other plankters, or both. The influence of the previous plankton population could operate in at least three ways: 1) through removal of some substance inhibitory to G. breve, 2) by excretion of a substance favorable to G. breve, or 3) by providing competition, perhaps through excretion of a substance detrimental to G. breve.

These quantitative data on other plankters, thus, need to be supplemented by laboratory work on the effect of these plankters, or of the water in which they have grown, on the growth of G. breve. It may be necessary to grow cultures of a number of plankters. These cultures should include forms that prey directly upon G. breve. If predatory forms could be encouraged by any feasible means, this type of control would be preferable to the use of nonspecific algicides.

At the meeting of the Advisory Committee at the 1958 symposium (USFWS, 1958) Rice suggested that field observations be made in an area outside the areas in which red-tide outbreaks normally occur. Comparison of chemical, physical, and biological data from the two areas might serve to isolate one or more causative factors.

Control Methods

Control methods have been discussed at some length in the section "Control of outbreaks." Here we discuss only new or untried methods.

The chief deterrent to the use of nonspecific algicides is the possibility of inflicting serious damage to other forms. If applied carefully in concentrations just high enough to kill G. breve, this damage will be chiefly to plankton, including larval forms. Since dinoflagellates tend to concentrate in convergences because of their ability to resist vertical currents, it might be feasible to control the red-tide organisms by treatment of the convergences only and, thus, inflict minimal damage to other forms. This end might be accomplished by gradually diffusing the algicide from floating material, such as coarse sawdust.

Algae in fresh water lakes have been successfully controlled by the use of aniline dye (Eicher, 1947). In a 200-acre lake averaging 10 feet deep, nigrosine dye was applied at 10 pounds per acre. The water became black, and 18 months later retained about 50 percent of its dark color. One very noticeable effect was the lowering of the pH. Whether it is feasible to shield the light by use of dyestuffs, or perhaps some cheaper material, sufficiently to affect G. breve significantly should be investigated.

Need for Coordinated Research

It has become abundantly clear that research on red tide involves several disciplines--both physical and biological oceanography, microbiology, analytical chemistry, biochemistry, and mathematics; several types of physical equipment and infinite patience also

are needed. Above all, a steady level of funding is required. Emergency funds are of slight value, regardless of amount, compared to a moderate but reliable budget. One cannot do excellent basic research if he is required to fire investigators periodically and then hire whatever personnel are unemployed when funds become available.

So much work still is needed, despite the fine work already completed, that duplication of effort should be avoided--although in science duplication is seldom wasteful because, by the very nature of research, no two people ever approach a problem in exactly the same manner. We would recommend, however, that Federal, State, and university personnel arrange for periodic discussions and continue their spirit of friendly teamwork in the interest of effective research.

REFERENCES PERTAINING TO RED TIDE AND RELATED SUBJECTS

ABBOTT, B. C., and DOROTHY BALLANTINE.
1957. The toxin from Gymnodinium veneficum Ballantine. J. Mar. Biol. Ass. U.K. 36(1): 169-189.

The toxin produced by dinoflagellates and causing paralytic shellfish poisoning may be different from that of other dinoflagellates associated with mass mortality of fish. The authors were unable to render shellfish poisonous with it and stated that Fingerman et al. (1953) indicated that the paralytic shellfish poison operates in a curarelike manner, while they showed that Gymnodinium toxin depolarizes the excitable membrane.

ALDRICH, DAVID V.
1958a. Histological techniques for Gymnodinium spp. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 94.

"The fragility of G. breve is clearly indicated by results obtained with usual histological fixatives. Formalin, Bouin's, Zenker's, and Schaudinn's fluids yielded only a very occasional recognizable cell. Alcohol, acetone, and trichloracetic acid also left few intact organisms, and iodine vapor, Lugol's solution, and a mixture of chromic and acetic acids were only slightly better. Best results have been obtained with 0.5 cc. of 1% osmic acid per 10 cc. of G. breve culture. This method will best preserve the living appearance of the organism, yielding about 70 percent of the live cells in recognizable condition."

ALDRICH, DAVID V.
1958b. Toxicity of copper to marine organisms. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 86.

"A series of copper toxicity studies is being conducted to compare the sensitivity to copper poisoning of several organisms representative of the Galveston Island Lagoon. . . .

"To date, the studies suggest that several Lagoon organisms may be arranged in this order of decreasing susceptibility to copper: Littorina, young sciaenids, young sparids, young mullet, grass shrimp (embryonated eggs as well as large and small adults)."

ALDRICH, DAVID V.
1959. Physiological studies of red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 69-71. U.S. Fish Wildl. Serv., Circ. 62.

"A study of the effect of pH on growth of G. breve in bacteria-free cultures shows that growth is unhampered by pH's of 7.5 to 8.3, inclusive. Growth took place at a reduced rate at a pH of 7.3, and lower values were definitely toxic. Medium having a pH of 7.2 was 100 percent lethal to this organism within six days, while 7.0 killed all cells within two days. [p. 69.]

"Over 800 individual cultures of G. breve have been exposed to specially controlled temperature conditions . . . . the organism did not survive temperatures of 7° C. and below, or 32° and above. Population growth did not occur at 30° (or above) and survival was very poor. Multiplication was visibly slowed at 15° C., but not completely halted. It is apparent that the level at which temperature becomes absolutely limiting to growth lies between 7° and 15° C., but the work which will determine this level more exactly is not yet complete. Optimal growth can occur in a range of temperatures including 20° to 27° C. . . . [p. 69.]

"These results strongly suggest that temperature can be an important factor in limiting the geographic distribution of G. breve. In this regard it may also be noted that Florida red tides occurring in the fall have ceased with the advent of the first cold weather of the subsequent winter." [p. 70.]

ALDRICH, DAVID V.

1960. Physiology of the Florida red tide organism. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 40-42. U.S. Fish Wildl. Serv., Circ. 92.

The red-tide "organism seems unable to tolerate fresh or brackish water and thus probably subsists offshore between red tides." [p. 40.]

The optimum laboratory temperature range for growth of pure G. breve culture is said to lie between 15° and 30° C. ". . . it is apparent that G. breve can tolerate slow temperature variations better than rapid ones. . . ." [p. 40.]

Parent stocks were grown at 25° C., and parental influence on survival of cultures at varying temperatures is questioned. Results of tests to determine parental influence were not conclusive.

"The culture work of W. B. Wilson demonstrates G. breve to be capable of autotrophic nutrition. . . ." [p. 40.]

Seventeen carbohydrates were tested and none were "found to support G. breve populations in the absence of light. . . . At this early stage of the work there is no evidence that this organism can derive energy directly from any source other than light." [p. 41.]

Varying light intensities showed that light intensity is probably not a growth-limiting factor above the 200 ft.-c. (foot-candle) level.

The organisms were destroyed under ultraviolet light and showed a preference for blue or green light.

The organisms also seem to prefer polarized light, and "cell counts to date suggest that polarized light may stimulate more rapid growth than ordinary light." [p. 42.]

ALDRICH, DAVID V.

1961. Culture and nutrition of Gymnodinium breve. In Galveston Biological Laboratory fishery research for the year ending June 30, 1961, p. 58. U.S. Fish Wildl. Serv., Circ. 129.

". . . We have recently compared the growth of G. breve in water from several rivers in red-tide and non-red-tide areas. A completely defined artificial sea water, incapable of supporting growth by itself, was employed as a diluent for the river waters. The Alafia, Hillsborough, Peace, and Caloosahatchee Rivers of Florida and the Atchafalaya and Sabine Rivers of Louisiana and Texas were tested. Growth occurred only with the addition of Hillsborough or Peace River water."

ALDRICH, DAVID V.

1962. Photoautotrophy in Gymnodinium breve Davis. Science 137(3534):988-990.

Extensive experiments failed to show evidence of heterotrophy. G. breve requires light and CO_2 for growth and survival.

"If Florida west coast rivers do not provide direct energy sources for multiplication of G. breve, the organism's vitamin, trace-metal, and chelator requirements assume added ecological significance as factors potentially limiting population growth. . . ." [p. 990.]

ALDRICH, DAVID V., and WILLIAM B. WILSON.

1960. The effect of salinity on growth of Gymnodinium breve Davis. Biol. Bull. (Woods Hole) 119(1):57-64.

Bacteria-free cultures were grown in test tubes in an artificial medium. Tubes inoculated with 100 to 200 G. breve cells. Growth estimated by visual examination with microscope. Classified growth into 11 categories. Three top categories were arbitrarily defined as "peak populations." Rough calibration by actual count showed peak population estimates to contain not less than 750 cells per ml. and usually from 1 to several thousand per ml. Tubes examined at 4, 10, 18, 25, and 35 days. Seldom any growth after 35 days. Five experiments each with 9 salinity levels, and 10 tubes at each level. In first experiment salinity ranged from 6.3 to 41.1 p.p.t., in last four experiments from 22.5 to 46.0 p.p.t. Their suggested optimum salinity range for good growth of 27 to 37 p.p.t. agrees well with the computer analysis mentioned in the summary.

ALLEN, W. E.

1933. "Red water" in La Jolla Bay in 1933. Science 78 (2010):12-13.

Discoloration to "muddy red" or "dirty red" caused by Prorocentrum micans.

ALLEN, W. E.

1935. "Yellow water" in La Jolla Bay in 1935. Science 82(2127):325-326.

Yellow water (apparently harmless) was caused by a small unidentified flagellate, colorless and bearing four flagella.

ALLEN, W. E.
1943. "Red water" in La Jolla Bay in 1942. Trans. Amer. Microscop. Soc. 62(3): 262-264.

ALLEN, W. E.
1946. "Red water" in La Jolla Bay in 1945. Trans. Amer. Microscop. Soc. 65(2): 149-153.

ANDERSON, WILLIAM W.
1951. Gulf Fishery Investigations. In Annual report for fiscal year 1951, Branch of Fishery Biology, Fish Wildl. Serv., p. 31-33.

"Plankton collections have been made by conventional methods and by means of a high speed sampler and a newly devised continuous sampler. The latter methods are still in the experimental stage but results are promising.

. . . . .

"In comparison to areas like the California coast or the North Atlantic, plankton in the Gulf is sparse. Tows in those areas produce 8 to 10 times more plankton than comparable tows in the Gulf. It has become evident, too, that a greater abundance of plankton exists over the continental shelf than exists in waters beyond the shelf. A preponderance of fish eggs and larvae also has been found within the 100-fathom contour.

"Analyses for inorganic phosphate and nitrate have been completed on a total of 371 samples obtained on the first three cruises. It has become evident from these analyses that phosphate and nitrate concentrations are extremely low at all levels inside the 100-fathom contour. In that portion of the Gulf outside the 100-fathom contour, extremely low concentrations of phosphate and nitrate exist in surface waters, but rise steadily to a maximum between about 450 to 600 fathoms, below which their concentrations decrease slightly. [p. 31.]

. . . . .

"Results to date lend weight to the theory that, in general, waters of the Gulf of Mexico beyond the 100-fathom curve are relatively sterile. It may be stated tentatively that the economy of our fisheries is closely associated with that portion of the Gulf lying inside the 100-fathom contour, the inshore waters, and contiguous land areas.

. . . . .

"Sampling over a prearranged series of stations extending from the rivers to the 100-fathom contour for a study of the local oceanography, nutrients, and plankton, has been completed. Data collected are being analyzed. Phosphate concentrations in this area are in agreement with those found elsewhere in the Gulf inside the 100-fathom contour.

"All plankton collected during the past year has been examined and data have been set up on punch cards for analytical studies. [p. 32.]

. . . . .

"Culture studies on nutritional requirements of dinoflagellates and other marine organisms have been continued at the Service's Beaufort, North Carolina, Laboratory." [p. 33.]

ANDERSON, WILLIAM W.
1952. Gulf Fishery Investigations. In Annual report for the fiscal year 1952, Branch of Fishery Biology, Fish Wildl. Serv., p. 16-18.

"Effort expended in a new laboratory being set up for artificial culture of marine microorganisms will be directed toward understanding nutritional and environmental requirements for survival and multiplication of various organisms, particularly dinoflagellates. Results will be used in producing mass cultures to determine the role of various organisms in production and utilization of various organic compounds which are being isolated from sea water. These results in turn, will be applied to studies on young fish survival.

"Red tide research.--A theory has been formulated that 'red water' depends on occurrence of isolated nonmixing water masses. A study of small-scale 'red waters' in some inland bays and information from various other sources support this hypothesis." [p. 18.]

ANONYMOUS.
1881. Mortality of fish in the Gulf of Mexico. Ann. Mag. Natur. Hist. 5(8):238-240.

This article cited from Hutton (1956) apparently contains same information as in Moore (1882).

ANONYMOUS.
1883. Poisoned water in the Gulf of Mexico. U.S. Fish Comm., Bull. 2:104. [Cited by Hutton (1956) as from the Sunland Tribune, Tampa, July 20, 1882.]

"We learn from Capt. William Jackson, of the steamer 'Lizzie Henderson,' that on his trip from Cedar Key, Tuesday, he encountered a streak of poisoned water, covered with all varieties of dead fish, of more than a mile in extent, off Indian Pass, between Clear Water and Egmont Light. The captain says that a very offensive smell arose from it, and that a good many bottom fish, such as eels, were floating dead on the surface. We opine that this fact upsets the theory of some as to this poisoned water being fresh water from overflow on the mainland, impregnated with poisoned vegetable matter, as there are no streams of any size flowing into the Gulf near where these fish were found."

ANONYMOUS.
1934. Chemicals repulse ravages of "red tide." Sci. Amer. 151(4):200-201.

"Turning back the 'red tide,' which periodically sweeps in from the sea to wreak havoc with the pearl-oyster beds along the coast of Japan, is one of the most recent and romantic applications of modern chemistry. Large areas of the sea along the Ise Bay are used for the cultivation of pearl-oysters and the jewels produced by the crustaceans are the basis of a large and prosperous Japanese industry. But even the pearl growers have their trials and tribulations, for now and then the 'red tide' appears--an onslaught of red micro-organisms, so small that 25,000 of them have plenty of room to circulate in a single cubic centimeter of sea water. But they color the water red--and they cause millions of dollars worth of damage each year to the pearl-oyster beds.

"Japanese chemists have found that they can halt the ravages of the 'red tide' by diffusing certain chemicals through the oyster bed. A solution of ferric chloride does the trick; so does chlorine gas. Motor boats have been rigged up with apparatus to spread these chemicals through the infested areas by discharging a stream of them from the stern of the boat in such a way that they are churned into the water by the propeller."

ANONYMOUS.
1953. Factors in "red tide" outbreak of 1952. Progr. Fish-Cult. 15(3):128.

A two-paragraph note on progress in research during 1952.

ANONYMOUS.
1956. The red tide--a progress report. First Nat. Bank of Dunedin, Dunedin, Fla., Bull. 1(6):1-11.

"Similar occurrences of varying intensity have been reported along Florida's West Coast both before and after the outbreak of 1947. Earliest chronicle is by Capt. William Jackson. On a trip from Cedar Key in 1842 he encountered 'a streak of poisonous water covered with all varieties of dead fish, of more than a mile extent, off Indian Pass, between Clearwater and Egmont light.' Fish kills were reported subsequently in 1854, 1878, 1880, 1882, 1883, 1885, 1908, 1916, 1932, 1946-47, 1951, 1952, 1953 and 1954. There have been independent recurrences within less than one year of each other while periods of at least fourteen years have elapsed with no reported outbreak. [p. 3.]

. . . . .

"...There are plans this summer [1956] for further study with visible tracing materials of the flow of river discharge into the Gulf...." [p. 11.]

The 1842 date was doubtless 1882 (see Anonymous, 1883).

ARMSTRONG, F.A.J., and G. T. BOALCH.
1961. The ultra-violet absorption of sea water. J. Mar. Biol. Ass. U.K. 41(3): 591-597.

Shows light absorption of micropore (1 μ) filtered sea water at several wave lengths and suggests differences between water from different localities are due to organic matter.

ARNOLD, EDGAR L., JR.
1958. Gulf of Mexico plankton investigations: 1951-53. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 269, vi + 53 p.

Presents the volumes of plankton, fish eggs, and fish larvae captured by four types of collecting gear in 449 tows from the research vessel Alaska in the Gulf of Mexico from March 1951 to July 1953.

BALLANTINE, DOROTHY, and B. C. ABBOTT.
1957. Toxic marine flagellates; their occurrence and physiological effects on animals. J. Gen. Microbiol. 16(1):274-281.

This paper includes a map showing "the world-wide distribution of 'red tides' where mortalities have been shown to occur.... [p. 274.]

. . . . .

"Blooms occur only when a number of parameters are simultaneously suitable...." [p. 276.]

Bioassays were conducted with toxin from Gymnodinium veneficum from the Plymouth area.

"Experiments have been carried out with a wide range of animals, and all except polychaetes are affected to a greater or lesser extent. In particular small fish, mainly gobies, have been used as test animals; these die within 10 min. in toxic cultures. Death in fish seems to be due to some form of respiratory failure. The action of the toxin is certainly on the nervous system. The first symptoms are a complete loss of balance, combined with an intense change of colour pattern. This is followed by a period of violent gasping, and intermittent unco-ordinated bursts of movement. During the quiescent intervals, which become progressively longer, there is no response to sensory stimulation. At the point of death there is no sign of haemolysis in the blood, the heart is beating, and excised muscles respond to direct stimulation.... [p. 277.]

"...The toxin acts by depolarizing excitable membranes, rendering them inexcitable. Both nerves and muscles are affected, but in the intact animal death occurs because of interference with transmission in the nervous system. The effect is reversible in isolated tissues, but the whole animal cannot dispose of the toxin...." [p. 278.]

The authors conclude that "in the case of the G. veneficum toxin the effect is due to membrane depolarization rather than to a curare-like inhibition of response to acetylcholine." [p. 280.]

BARKER, H. A.
1935. The culture and physiology of the marine dinoflagellates. Arch. Mikrobiol. 6(2):157-181. [Cited from Ryther, 1955.]

Ryther said, "Barker (1935), who is one of the pioneers in developing successful culture methods for dinoflagellates, observed optimal temperatures for growth of some 14 species between 18° and 25° C."

BAUGHMAN, J. L.
1947. The Florida red tide. Texas Game Fish 5(12):6, 20-21.

BECKING, L. B., C. F. TOLMAN, H. C. McMILLIN, JOHN FIELD, and TADAICHI HASHIMOTO.
1927. Preliminary statement regarding the diatom "epidemics" at Copalis Beach, Washington, and an analysis of diatom oil. Econ. Geol. 22(4):356-368.

"The epidemics occur:

1. Towards the end of the rainy season in April and May.
2. After a heavy rainstorm.
3. When the rains are followed by gentle westerly winds.
4. And they reach a maximum when the rain is followed by clear weather and bright sunshine." [p. 358.]

In 1925 thousands of tons of the diatoms (Aulacodiscus kittoni Arnott) were washed ashore, covering the beach with a mass 4 to 6 inches thick.

BEIN, SELWYN JACK.
1954. A study of certain chromogenic bacteria isolated from "red tide" water with a description of a new species. Bull. Mar. Sci. Gulf Carib. 4(2):110-119.

The author described a chromogenic bacterium, which he named Flavobacterium piscicida. This bacterium was isolated from colored water with a yellowish cast. He cultured the bacteria and performed several experiments in which fish died when held in 4-gallon tanks to which a half-liter of a 24-hour culture of the bacterium was added. He suggested that since this bacterium is capable of killing fish under laboratory conditions it possibly had a role in the mortality from "Red Tide" outbreaks.

BEIN, SELWYN JACK.
1955. Red tide bacterial studies. Univ. Miami, Mar. Lab., Spec. Serv. Bull. 10:1-2.

"The conclusions drawn from these experiments are as follows: The fish are killed by a water soluble, toxic material, produced by the growth of the bacteria. The toxin is thermolabile, that is, unstable at high temperatures, but extremely poisonous under natural climatic conditions. Given the correct conditions these organisms appear capable of 'blooming' and causing mass mortality of marine organisms in nature." [p. 2.]

BEIN, SELWYN JACK.
1957. The relationship of total phosphorus concentration in sea water to red tide blooms. Bull. Mar. Sci. Gulf Carib. 7(4):316-329.

The total phosphorus concentrations from both published and unpublished data were examined to note concentration before, during, and after red-tide

outbreaks. He used data from Ketchum and Keen (1948), Graham et al. (1954), Chew (1953), Lackey and Hynes (1955), and data taken by the Marine Laboratory, not already published, from the vicinity of Gasparilla Island in 1954 and 1955.

Total phosphorus values showed great variation that appeared to have no relation to red tide. For instance, a series of 98 observations at 28 stations around Gasparilla Island in the fall of 1952, during a period without red tide, averaged 14.74 ug.at./l., with a maximum of 60 ug.at./l. These are higher values than the few observations in sea water from red-tide blooms analyzed by Ketchum and Keen (1948).

The fact that some reports consistently gave very low phosphorus values, while others gave consistently high values, causes us to speculate on the difference in analytical techniques that may have been used.

The author stated, "In periods of Red Tide outbreaks the total phosphorus content of a bloom, including the organisms and particulate phosphorus, is lower than the maximum values recorded in 'normal' years and, with the exception of Ketchum and Keen's values, is not significantly different from the adjacent areas with no Red Tide examined at the same period. At many times and places examined in the absence of Red Tides or blooms, Florida west coast waters contained at least as much and often more than the estimated order of magnitude of total phosphorus contained in a heavy plankton bloom. The total phosphorus values of Lackey and Hynes (op. cit.) for Red Tide stations, which were analyzed with the organisms in the samples, are unusually low for any type of plankton bloom and there is no obvious explanation for these figures." [p. 327-328.]

The author concluded, "...It is possible that the threshold level of total phosphorus necessary to support dense populations of this organism is lower than originally assumed. The fact that the waters under consideration are usually rich in this mineral has perhaps led to much of the confusion in dealing with this problem. It seems very probable that, insofar as phosphorus is concerned, the areas of the west coast of Florida which have recorded Red Tides are, at all times, capable of supporting an outbreak. Since the total phosphorus content may no longer be considered a limiting factor here it has no value in predicting outbreaks." [p. 328.]

BHIMACHAR, B. S., and P. C. GEORGE.
1950. Abrupt set-backs in the fisheries of the Malabar and Kanara coasts and "red water" phenomenon as their probable cause. Proc. Indian Acad. Sci. B31:339-50. [Cited by Ryther, 1955.]

Describes a bloom of Noctiluca miliaris occurring along the Malabar Coast in October 1948, after the southwest and before the northeast monsoon, during calm, hot weather, with a salinity of about 35 p.p.t.

BONNOT, PAUL, and J. B. PHILLIPS.
1938. Red water, its cause and occurrences. Calif. Fish Game 24(1):55-59.

"During the last three weeks in August and the first two weeks in September, 1937, the ocean water from Pt. Sur to Pt. Reyes was affected in varying degree with red water. It was not distributed uniformly throughout the above region but appeared in streaks and patches. It was first noted in Monterey Bay about August 11, appearing as a streak paralleling shore. This streak was about 100 yards wide and commenced approximately 200 feet offshore. Later this was scattered over a wider area, apparently by tide and wind. Other streaks and patches appeared farther offshore. Fishermen reported seeing this discolored water as far south as Pt. Sur and as far north as Pt. Reyes. Areas of red water were also reported in the San Pedro region by W. L. Scofield, so it appears that other localities along the Pacific Coast were affected at this time. The presence of red water in the Monterey region during the above period was the most extensive and persistent plague recorded for this area.

"The organisms responsible for the red water epidemic in the Monterey-San Francisco region during August and September, 1937, have been identified by H. W. Graham of the Carnegie Institution, Washington, D.C., as of the genus Gonyaulax, species G. catanella or a very similar form." [p. 57.]

BRAARUD, TRYGVE.
1945. A phytoplankton survey of the polluted waters of inner Oslo Fjord. Hvalrådets Skr. 28, 142 p. [Cited from Ryther, 1955.]

BRAARUD, TRYGVE.
1951. Salinity as an ecological factor in marine phytoplankton. Physiol. Planatarium 4:28-34. [Cited by Ryther, 1955.]

BRAARUD, T., and I. PAPPAS.
1951. Experimental studies on the dinoflagellate Peridinium triquetrum (Ehrb.)

Lebour. Avhandl. Norsk. Vid.-Akad., Oslo, Mat.-Naturv. Klasse (1951) 2:1-23. [Cited from Ryther, 1955.]

BRAARUD, T., and E. ROSSAVIK.
1951. Observations on the marine dinoflagellate Prorocentrum micans Ehrenb. in culture. Avhandl. Norsk. Vid.-Akad., Oslo, Mat.-Naturv. Klasse (1951) 1:1-18. [Cited from Ryther, 1955.]

BRONGERSMA-SANDERS, MARGARETHA.
1945. The annual fish mortality near Walvis Bay (South West Africa), and its significance for paleontology. Arch. Neerland Zool. 7:291-294. [Cited from Pomeroy et al., 1956.]

Upwelling of water into photic zone is given as a source of nutrients.

BRONGERSMA-SANDERS, MARGARETHA.
1948. The importance of upwelling water to vertebrate paleontology and oil geology. Verhandl. Koninkls. Nederland. Akad. Wetenschap., afd. Natuurk., Tweede Sectie 45(4):1-112. [Cited by Ryther, 1955.]

Blooms of Noctiluca sp. appeared to cause annual mass mortalities in Walvis Bay, South West Africa, in December. Mortalities were during periods of minimum upwelling and the highest water temperature of the year.

BRONGERSMA-SANDERS, MARGARETHA.
1957. Mass mortality in the sea. In Joel W. Hedgpeth (editor), Treatise on marine ecology and paleoecology, vol. 1, ch. 29, p. 941-1010. Geol. Soc. Amer., Mem. 67.

Mass mortality in sea caused by noxiousness of waterbloom [p. 951].

"Red water occurs in very fertile parts of the sea, often during or after unusually warm weather; it develops in succession after a great production of other organisms. Products of decay of the latter might be one factor that sets the bloom in motion. Great outbreaks occur particularly in subtropical and tropical regions where the rate of overturn of organic matter is high; in fertile parts of high latitudes red water, at least of catastrophic proportions, does not occur or is very rare. Plenty of sunshine seems another requirement for red-water outbreaks. The areas where red water occurs are somewhat reminiscent of polluted waters; the dead fish will worsen the 'pollution'. Here it is important to note that pollution by human action also favors red-water outbreaks....

"The greatest outbreaks of red water probably occur toward the end of a phytoplankton season; in areas where upwelling occurs during part of the year only, red water usually develops toward the end or directly after the period of upwelling...." [p. 953.]

BRUNEL, J., G. W. PRESCOTT, L. H. TIFFANY ET AL.
1950. The culturing of algae. Charles F. Kettering Found. p. I-IX, 1-114. [Non vidi.]

Contains an extensive bibliography on culturing of algae and summarizes work on culturing.

BRYAN, ARTHUR H.
1963. The red tide. Amer. Biol. Teacher 25(1):53-54. [Cited from Biol. Abstr. Non vidi.]

BUCK, JOHN D., SAMUEL P. MEYERS, and EINAR LEIFSON.
1963. Pseudomonas (Flavobacterium) piscicida Bein Comb. Nov. J. Bacteriol. 86(5):1125-1126.

Discovered the organism to be polar monotrichous rather than peritrichous as originally described by Bein (1954). Culture filtrates were toxic to the top minnow Gambusia sp.

BURKHOLDER, PAUL R., and LILLIAN M. BURKHOLDER.
1956. Vitamin B_{12} in suspended solids and marsh muds collected along the coast of Georgia. Limnol. Oceanogr. 1(3):202-208.

Appreciable amounts of vitamin B_{12} are carried on suspended particles in river water, up to 6.4 micrograms per gram of solids. On particulate matter in sea waters vitamin B_{12} varied from 0.0027 to 0.130 microgram per liter.

BURR, J. G.
1945. Science tackles a mystery. Texas Game Fish 3(9):4-5, 24-25.

"On June 27, 1935, ten years ago, the Texas coast was rocked by the most sensational event in its history, when millions of pounds of fish were destroyed in the Gulf of Mexico by some unknown cause. This destruction of fish continued for a period of five weeks or more as evidenced by dead fish which lined the shore for 150 miles, beginning along the shore of Padre Island, and extending nearly to the area of Freeport...for two months prior to the fish tragedy rainfall had been unprecedented,

and the four major rivers from the Brazos to the Nueces River, in the months of May and June, had dumped 10,000,000-acre feet of water into the Gulf." [p. 4.]

BURSA, ADAM.
1963. Phytoplankton in coastal waters of the Arctic Ocean at Point Barrow, Alaska. Arctic 16(4):239-262.

Lists 73 species (one new) in 20 genera of dinoflagellates collected between mid-June and mid-September of 1954. Maximum temperature in August was 10.2° C.

CABASSO, V., and H. ROUSSEL.
1942. Essai de explication du phénomène dit "Des eaux rouges" du lac de Tunis. Arch. Inst. Pasteur, Tunis, 31(3/4):203-211.

CAHN, A. R.
1949. Pearl culture in Japan. Natur. Resourc. Sect. Supreme Commander Allied Powers, Tokyo, Rep. 112, 91 p.

Describes the destruction of pearl oysters by red tide.

CAHN, A. R.
1950. Oyster culture in Japan. Fish Wildl. Serv., Fish. Leafl. 383,80 p.

"The 'akashio' or red tide is an aquatic phenomenon that occurs at irregular intervals and with variable intensities and results. It may be highly destructive not only to edible oysters but also to the pearl oysters (Cahn, 1949) and to other forms of marine life. In recent years the microorganisms which cause the red tide in Japan have been shown to be various dinoflagellates such as *Gonyaulax*, *Gymnodinium*, *Peridinium*, *Ceratium*, and other forms of lesser importance. [p. 60.]

. . . . .

"Red tides occur mostly in the spring and autumn where the ocean current is sluggish, usually during continuously fine, quiet weather.... Many red tides do little or no damage to oysters, while others result in a mortality approaching or reaching 100 percent.... Experiments using copper sulfate are inconclusive." [p. 60.]

CANOVA, ANDREW P.
1885. Life and adventures in south Florida. South Sun Publ. House, Palatka, Fla. 136 p. [Cited from Lackey and Hynes, 1955.]

Canova reportedly mentioned a "green tide" in 1885 that might have been as intense as later outbreaks but less irritating to the then small tourist industry.

CARTER, H. J.
1858. Note on the red colouring matter of the sea round the shores of the island of Bombay. Ann. Mag. Natur. Hist., 3d ser., 1(4):258-262.

He attributed the discolored water to a form which he named *Peridinium sanguineum*.

CHEW, FRANK.
1953. Results of hydrographic and chemical investigations in the region of the "Red Tide" bloom on the west coast of Florida in November 1952. Bull. Mar. Sci. Gulf Carib. 2(4):610-625.

He reported the "signs of another bloom off Dry Tortugas on January 3, 1953, and subsequent airplane observations disclosed suspicious areas. A definite recurrence was detected off Smith Shoal on January 22, 1953. This, too, was of brief duration...." [p. 610.] Off Fort Myers red tide occurred in November 1952; 11 hydrographic stations were occupied (actually 12 stations).

Each of the 12 stations was occupied once during a period of 3 days. The depths were 7 to 13 m. and observations of salinity, temperature, and total phosphorus were taken at surface, bottom, and middepth. The author attempted by means of hydrographic sections to postulate "river water" and "Gulf water" in the small near-shore area involved; however, the few data, the slight difference in salinity, and the use of straight line interpolation of values where there is no consistent pattern, all make the exercise appear tenuous.

CHEW, FRANK.
1955a. On the offshore circulation and a convergence mechanism in the red tide region off the west coast of Florida. Trans. Amer. Geophys. Un. 36(6):963-974; also Tech. Rep. 55-5, Fla. State Bd. Conserv., 27 p.

In this article the author discussed a mechanism to concentrate floating particles. He quoted from several observations concerning floating dead fish, and then reached the conclusion that, "The large horizontal dimensions of these patches of dead fish preclude the phenomenon from being oversized windrows or resulting from causes related to the wind [Stommel, 1951]....

In the next paragraph he stated, "The observed outbreaks of Red Tide at beaches generally show a sequence of south to north movement...." Recent

outbreaks have not shown such tendency. The author then said, "The remaining portion of this paper discusses the offshore circulation in an attempt to find the mechanics of the northward and shoreward movement." (italics ours). [p. 963.]

In advancing his thesis the author placed heavy weight on the few phosphorus samples analyzed by Ketchum and Keen (1948). Actually, the values which Ketchum and Keen observed were not as exceptional as comment at the time would have us believe. Their values for total phosphorus in red-tide water have often been exceeded by samples from nonred-tide water collected by the Bureau of Commercial Fisheries. Exceptionally high phosphorus values often occur in nonfiltered samples because of particulate matter. This refutes their statement, quoted in Galtsoff (1948, p. 21),"... These values are from 5 to 10 times as high as those ever encountered in uncontaminated oceanic water...."

In advancing his theory of the offshore derivation of phosphorus-rich water, Chew stated, "... The shoreward tendency during a Red Tide bloom was noted earlier by Chew [1953] who concluded that high total phosphorus waters were advected toward shore from the open Gulf; the work of Ketchum and Keen [1948] is also of significance in this respect, since their highest observed total phosphorus was found at their farthest offshore stations....." [p. 972.] A completely opposite picture would be obtained from the data from the 16-month survey of phosphorus by the Bureau of Commercial Fisheries (Graham et al., 1954).

In the discussion of water movements Chew did not separate floating dead fish from red tide. Actually, they are not the same and cannot be expected to act in the same way.

In his summary Chew stated that "... The mortality generally moves northward and shoreward...." [p. 973.] Regarding this conclusion he cited Gunter et al. (1948) and one issue of a St. Petersburg newspaper.

Chew also made a second conclusion in which he said, "During periods of Red Tide mortality, it is generally believed that there is a large band of dead fish some tens of miles offshore. The horizontal dimensions of the band are several miles wide and 20 to 30 mi. long...." [p. 973.] See, for example, Nicholson (1954). This band of dead fish appears to be a necessary part of his theory of red tide origin and water movement.

CHEW, FRANK.
1955b. Red tide and the fluctuation of conservative concentrations at an estuary mouth. Bull. Mar. Sci. Gulf Carib. 5(4): 321-330.

This paper was based on salinities taken in a row of eight stations on May 28, 1954, over one tidal cycle of 14 hours. The paper attempted to show that if red tide requires a particular salinity, such as that found at the mouth of an estuary, this salinity may be found best at times of greatest mixing. This paper stressed salinity as the cause of red tide. Other explanations, however, were also given. For instance he stated, "It has been suggested that observed Red Tide outbreaks have tended to fall near periods of spring tides. Since from equation (11) one sees that the transition zone near the estuary mouth is weak during these periods, one is led to the conclusion that an effect of spring tide on Red Tide outbreaks is due to other causes, such as stirring of the estuary bottom, than the presence of a strong, sharp transition zone at the estuary mouth." [p. 329.]

CHEW, FRANK.
1955c. The summer circulation of the Florida west coast offshore water as deduced from the pattern of thermocline depths and a non-geostrophic equation of motion. Rep. to Fla. State Bd. Conserv., Tech. Rep. 55-12, 6 p.

This paper advances a theory of water circulation based chiefly on BT readings from one August cruise of the vessel Alaska. The time period was not mentioned but from the markings on his figure 2 it appears to be about 1 week. This paper marks a step toward advancement of Chew's theory that the cause of red tide must be sought elsewhere, such as the Apalachicola River.

CHEW, FRANK.
1956. A tentative method for the prediction of the Florida Red Tide outbreaks. Bull. Mar. Sci. Gulf Carib. 6(4):292-304.

In this paper the hypothesis is advanced that red-tide outbreaks are caused by the mixing of estuarine waters carrying a terrigenous nutrient supply, with offshore waters. The Apalachicola River was taken by Chew as the source of the estuarine water. He said it is "seeded" by estuarine waters from Tampa Bay and Charlotte Harbor which contain the causative organism. His Red

Tide Index Number was synthesized from Apalachicola River runoff data and air temperatures for several localities. The Index appears to have been derived by working backward from effect to cause, and no measure was given of its reliability. One of the chief difficulties in deciding on causal factors has been the lack of good data on abundance of red-tide organisms.

His unsubstantiated theory requires that chunks of Apalachicola "estuarine water" move intact from Apalachicola to the vicinity of Boca Grande Pass and there acquire red-tide organisms.

CHIDAMBARAM, K., and M. D. ANNY.
1944. Note on the swarming of the planktonic algae, Trichodesmium erythraeum in the Pamban area and its effect on the fauna. Curr. Sci., Bangalore, 13(10):263.

CLASSEN, TH.
1930. Periodisches Fischsterben in Walvis Bay, South West Afrika. Palaeobiologica 3:1-13.

CLEMENS, W. A.
1935. Red "water-bloom" in British Columbia waters. Nature 135(3412):473.

"In Nature of September 22, 1934, there is a communication from Mr. T. John Hart describing the occurrence of a red 'water-bloom' caused by Mesodinium in South African seas. It may be of interest to record an occurrence of blood-red water at Nanaimo, British Columbia, during the week of April 28, 1933. The water in a channel immediately north of the harbour was coloured crimson red in great patches. Examination of a sample of the water revealed a pure culture of a ciliate, identified by Mr. G. H. Wailes as Mesodinium rubrum, Lohmann.

"About this time oysters in Ladysmith Harbour, fifteen miles south of Nanaimo, were reported to contain red 'worms.' Investigation disclosed the fact that the crystalline styles were coated with a red colouring matter, evidently as a result of feeding upon Mesodinium. Examination of the styles of local clams showed a similar condition.

"The appearance of this 'bloom' of Mesodinium followed a period of a couple of weeks of bright, sunny, calm weather. No discoloration was observed in 1934."

COLLIER, ALBERT W.
1953a. Gulf Fishery Investigations. In Annual report for fiscal year 1953, Branch of Fishery Biology, Fish Wildl. Serv., p. 20-21.

"Red tide research.--Data collected during the November 1952 red tide outbreak, which also killed millions of fishes off western Florida in 1946 and 1947 and has been ascribed to an excess of the dinoflagellate Gymnodinium brevis, show that Caloosahatchee River effluents are important agents in such blooms, and that organic content and physical attributes cause such activity. Experimental tank work indicates a mass growth of dinoflagellates as well as other organisms, requires high light intensity, vitamin B_{12} and sulfides.

"An examination of tidal streams, marshes and estuaries produced Gymnodinium brevis in Barfield Bay, south Florida. Field culture of this species was unsuccessful. Water from Lake Okeechobee was heavily loaded with dissolved organic materials.

"Daily collections and physical and chemical observations were made of dinoflagellates in Galveston, Texas, lagoons. Gymnodinium splendens, used in experiments as nearest to Gymnodinium brevis, was found.

. . . . . .

"Microbiology.--Light levels above those generally reported for algal culture have been found necessary for culture of some dinoflagellates indigenous to the Gulf coast. A ten-fold increase is now in use. Large-scale tank studies have proved valuable adjuncts to standard tube and dish cultures.

"Experimental ecology.--These experiments have been confined to a study of red tide. Large tanks have been set up for use as a 'stepping stone' from test tube to open sea. Findings on light level and value of certain inorganic nutrients result from this approach. These are important in analyzing interspecies on relationships. This work provides a basis for advanced studies of larval shrimp and fish behavior, survival and growth." [p. 21.]

COLLIER, ALBERT.
1953b. Titanium and zirconium in bloom of Gymnodinium brevis Davis. Science 118(3064):329.

Samples of water were analyzed from:
1. A dense bloom of G. brevis
2. Lake Okeechobee
3. Central Gulf of Mexico
4. A tidal lagoon at Galveston, Tex.

Titanium and zirconium were sufficiently abundant in sample 1 to exceed the sensitivity of the analytical method. No traces of either could be detected in the other four samples.

COLLIER, ALBERT W.

1954. Gulf Fishery Investigations. *In* Annual report for fiscal year 1954, Branch of Fishery Biology, Fish Wildl. Serv., p. 23-25.

"*Red Tide*.--When the September 1953 Red Tide outbreak occurred the microorganism *Gymnodinium brevis* was isolated and a medium evolved in which it could be grown as a unialgal culture (not bacteria free). In a series of experiments, tube cultures were enlarged to 10-liter tank cultures which culminated in development of small-scale blooms which were toxic to fish. The success with *Gymnodinium brevis* was made possible by success with cultures of a related species, *Gymnodinium splendens*. Cultures of the latter tested for toxicity on fish (*Membras* and *Mollienesia*) were nontoxic at concentrations of 3,000,000 cells per liter. *Gymnodinium brevis* was toxic at 1,300,000 cells per liter, a concentration which does not cause a pronounced water discoloration in the 5-gallon pyrex container where the culture is maintained. In the deeper waters of the Florida littoral regions, however, this concentration would cause the 'milky green' which often characterizes areas where fish are killed.

"These mass laboratory cultures are set up so cells can be harvested daily and the volume of total culture removed made up by adding fresh medium. Daily and biweekly sampling has been made for pH, carbon dioxide, nitrate nitrogen, phosphate phosphorus, carbohydrate, tyrosine, ammonia, and sulfide in these cultures. Metabolic studies on mass cultures are used in interpreting field data and will assist in diagnosing field conditions which can lead to a Red Tide.

"Field surveys which began with the September 1953 outbreak have shown Florida waters have never been entirely free of *Gymnodinium brevis*. Although suitable hydrographic conditions have been present to some degree through the whole period, it is unknown whether continued presence of *G. brevis* is because of these conditions or because of improved techniques for locating the organism when it is not in bloom. Data from laboratory and field studies support the tentative conclusion that optimum salinity for a bloom of this organism lies between 32 and 34 parts per thousand.

"Analysis of climatic factors has confirmed the theory that rainfall distribution is a prime factor in initiating fish kills.

"Laboratory experiments have further confirmed the theory that decaying fish bodies reinforce the blooms." [p. 24-25.]

COLLIER, ALBERT W.

1955. Gulf Fishery Investigations. *In* Annual report for fiscal year 1955, Branch of Fishery Biology, Fish Wildl. Serv., p. 29-32.

"Support for the theory that residues of dead fish compound the division rate of *G. brevis* comes from an explosive bloom in the laboratory which was created by adding juices from fish killed experimentally by a relatively low concentration of *G. brevis*. The initial concentration was about 3,000,000 individuals per quart; with the addition of juices they tripled in number overnight.

. . . . .

"*Red tide control*.--If control is possible, it will come after development of techniques for predicting conditions which are conducive to a red tide outbreak and for economical distribution of chemical or physical agents lethal to *G. brevis*. Predictions are necessary to make the latter possible.

. . . . .

"A search for lethal agents has revealed that metallic copper and copper salts are most toxic. Copper sulphate at approximately 0.12 p.p.m. (copper equivalent 0.05 p.p.m.) in sea water is lethal to *G. brevis*. A small piece of copper metal will make a pint of sea water lethal to *G. brevis* in a few seconds. An experiment in which fine copper sulphate was spread over the sea surface with crop-dusting planes was successful in eliminating the organisms for approximately one fourth of a square mile." [p. 31.]

COLLIER, ALBERT.

1958a. Gulf of Mexico physical and chemical data from *Alaska* cruises. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 249, vi + 417 p.

This reports the original hydrographic data collected from the vessel *Alaska* during the period March 1951 to July 1953.

COLLIER, ALBERT.

1958b. Some biochemical aspects of red tides and related oceanographic problems. Limnol. Oceanogr. 3(1):33-39.

The frequency distributions of sample values for carbohydrates, tyrosine, and organic phosphorus are given, and the author stated that "there was a tendency toward the contagious distributions."

Plotting shows that the carbohydrate values plotted logarithmically form a linear curve. Organic phosphorus definitely does not, and the tyrosine values do not, show a good linear fit. If, as many authors contend, plankton is distributed in one of the logarithmic series, it would not be surprising if carbohydrates, if derived from plankton, also fell into the two-parameter logarithmic series.

It was suggested that lethality of sea water from different localities may be caused by the interplay of lethal concentrations of copper and H_2S; also other "natural organic compounds" may act both as chelators and growth-promoting substances.

It was stated that W. B. Wilson isolated and cultured G. breve from Galveston waters and again from waters of "South Texas and Mexican east coasts."

The author stated that heavy blooms of red tide "may augment themselves with both inorganic and organic materials produced by the decomposition products of dead fish."

COLLINGSWOOD, C.
1868. Observations on the microscopic alga which causes the discoloration of the sea in various parts of the world. Trans. Roy. Microscop. Soc., n.s., 16:85-92.

CONNELL, CECIL H., and JOY BARNES CROSS.
1950. Mass mortality of fish associated with the protozoan Gonyaulax in the Gulf of Mexico. Science 112(2909):359-363.

Contains a report of fish kills in Offatts Bayou associated with Gonyaulax catenella (?) during the summer of 1949.

The authors indicated that:

1) Growth of Gonyaulax was increased by small amounts of sewer pollution.

2) As long as the organisms remained near the surface, the dissolved-oxygen content of the water was high. However, when the organisms submerged, the oxygen content rapidly approached zero. Only seven samples were taken in all.

3) "The values of biochemical oxygen demand (BOD) for the samples associated with Gonyaulax were extraordinary and far in excess of what might be explained by sewage or any other organic pollutant entering the bayou. . . . . It seems logical to assume that these extraordinarily high values of BOD and consequent anaerobic conditions in the water were attributable to the Gonyaulax and were important contributing factors in the mass mortality of fish in Offatts Bayou." [p. 362-363.]

CONOVER, SHIRLEY A. MacMILLAN.
1954. Observations on the structure of red tides in New Haven Harbor, Connecticut. J. Mar. Res. 13(1):145-155.

". . . High concentrations of red tide organisms, here two species of Goniaulax, were found to be associated with stable water masses of inner harbor origin. The configuration of the harbor permits the development and retention of water masses; this tendency is reinforced by large volumes of nutrient-rich fresh water entering the inner harbor, by certain wind patterns, and by high radiation values. Adequate time, illumination, nutrients, and favorable temperatures are essential for red tide development. . . ." [p. 145.]

CORNMAN, IVOR.
1947. Retardation of Arbacia egg cleavage by dinoflagellate-contaminated sea water (red tide). [Abstract.] Biol. Bull. (Woods Hole) 93(2):205.

Samples of red tide sea water supplied by Paul S. Galtsoff were used at the Marine Biological Laboratory in Woods Hole. A sample of untreated decomposing sea water "taken from an area stained red by Gymnodinium when diluted 1:10" increased cleavage time of the eggs of Arbacia by 1 hour (100 percent), "if added 10 minutes after fertilization." However, "when most of the H_2S was pulled off with a vacuum pump, the delay at 1:10 was only 3 minutes" and even at 1:5 only 15 minutes.

COVELL, W. P., and W. F. WHEDON.
1937. Effects of the paralytic shellfish poison on nerve cells. Arch. Pathol. 24(4): 412-418. [Non vidi.]

COWEY, C. B.
1956. A preliminary investigation of the variation of Vitamin B_{12} in oceanic and coastal waters. J. Mar. Biol. Ass. U.K. 35(3):609-620. [Cited from McLaughlin, 1958.]

CRANCE, JOHNIE H.
1963. The effects of copper sulfate on Microcystis and zooplankton in ponds. Progr. Fish-Cult. 25(4):198-202.

Copper sulphate ($CuSO_4.5H_2O$) at a concentration of 0.05 p.p.m. killed Microcystis without harming copepods or cladocerans.

DARESTE, CAMILLE.
1855. Memoire sur les animalcules et autres corps organises qui donnent a la mer une couleur rouge. Ann. Sci. Nat., Zool. 3:179-239. [Cited from Martin and Nelson, 1929.]

Gives numerous references to early writers and navigators concerning red tide.

DAVIS, CHARLES C.
1948. Gymnodinium brevis sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. Bot. Gaz. 109(3):358-360. [Contr. 17, Univ. Miami, Mar. Lab.]

"In April, 1947, there were further reports of fish mortality in the Gulf of Mexico off the Florida Keys. . . .

". . . Off Key West (near Content Keys) fish mortality was occurring in a situation in which the count of Gymnodinium was 420,000 cells per liter. . . Furthermore, the mortality of fish and other animals occurred sporadically over a period of 9 months from November, 1946, to July, 1947. . . ." [p. 358.]

Gymnodinium brevis is described as a new species, with an illustration. The chromatophores are described as yellow-green in color in both living and preserved specimens.

DAVIS, CHARLES C.
1950. Observations of plankton taken in marine waters of Florida in 1947 and 1948. J. Fla. Acad. Sci. 12(2):67-103.

Lists plankton species taken in Florida waters (chiefly west coast) during 1947. About half the samples were taken with a fine net (No. 20) and several of them contained large numbers of Gymnodinium breve.

DAVIS, CHARLES C.
1955. The marine and fresh-water plankton. Mich. State Univ. Press, 562 p.

In early May 1948 the water of Middle Lake, Dade County, was green and opaque owing to the enormous abundance of Gonyaulax. The water of certain areas of Seven Palm Lake showed similar patches.

"Unpublished data in the possession of the author show that during the 'red tide' on the west coast of Florida, described by Gunter et al. (op. cit.), Gymnodinium brevis amounted to 99.28 per cent and 98.99 per cent of the total organisms in the water in two unconcentrated samples of sea water." [p. 83.]

DAVIS, CHARLES C., and ROBERT H. WILLIAMS.
1950. Brackish water plankton of mangrove areas in southern Florida. Ecology 31(4):519-531.

Plankton samples were collected during the first half of 1948 (plus four samples in June 1947) from 28 localities in the mangrove area of the Everglades, between Everglades City and Barnes Sound. Salinities are given on dates of collection.

De SOUSA e SILVA.
1953. "Red water" par Exuviella baltica Lohm. Com simultânea mortalidade de piexes nas âguas litorais de Angola. Trab. Missâo Biol. Marit. 4, Lisboa. [Non vidi.]

Analyzed red-tide plankton samples from Luanda (see Nümann, 1957).

DENISON, W.
1862. On the death of fishes during the monsoon off the coast of India. Quart. J. Geol. Soc. Lond. 18:453.

DRAGOVICH, ALEXANDER.
1958. Hydrography related to red tide. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 70-75.

Copper, total phosphate-phosphorus, inorganic phosphate-phosphorus, and nitrate-nitrites in the coastal water of west Florida are subjects of this report.

DRAGOVICH, ALEXANDER.
1959. Environmental hydrology in relation to red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 80-85. U.S. Fish Wildl. Serv., Circ. 62.

"One of our objectives is to determine whether the outflow of the Hillsboro, Alafia, Little Manatee and Manatee Rivers influences the phosphorus content of Tampa Bay and adjacent neritic waters. . . . . The water of upper Tampa Bay (subarea 2) contained more phosphorus than any of the rivers, except the Alafia. These data indicate that phosphorus may, on occasions, accumulate in this portion of Tampa Bay.

. . . . .

"In March, a month of heavy rainfall, a drastic increase in phosphorus content was noted in all areas except at stations located 20-40 miles offshore. In April and May, the precipitation continued to be heavy and in May a nominal increase of phosphorus content in the areas 20 to 40 miles offshore was observed...." [p. 82.]

DRAGOVICH, ALEXANDER.
1960a. Copper in Tampa Bay and adjacent neritic and river waters. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 65. U.S. Fish Wildl. Serv., Circ. 92.

Information in this progress report published in Dragovich and May (1963).

DRAGOVICH, ALEXANDER.
1960b. Hydrology of Tampa Bay and adjacent waters. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 48-51. U.S. Fish Wildl. Serv., Circ. 92.

"Comparison of the water temperatures with incidence of G. breve indicates that a relation to temperature may exist, especially during the cold periods. During the winter [59-60] the temperature of water 20-40 miles offshore was higher than that of inshore waters. This may be important in the survival of G. breve offshore...." [p. 48.]

It was suggested that "the size of a G. breve population may be important for its survival in Tampa Bay during the onset of a rainy season when a drastic reduction of salinity occurs." [p. 49.]

It was also suggested that it is possible for surface waters with a slightly reduced salinity to exist at 30 to 40 miles offshore.

The author said that the greatest amount of phosphorus is brought into Tampa Bay by the Alafia River, and the greatest proportion of phosphorus is introduced at the beginning of the rainy season.

"...No relationship was observed between the incidence of G. breve and nitrate-nitrites." [p. 51.]

DRAGOVICH, ALEXANDER.
1961. Relative abundance of plankton off Naples, Florida, and associated hydrographic data, 1956-57. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 372, iii + 41 p.

Original data from Naples, Fla., for the period March 1956 through August 1957.

DRAGOVICH, ALEXANDER.
1963. Hydrology and plankton of coastal waters at Naples, Florida. Quart. J. Fla. Acad. Sci. 26(1):22-47.

In this report on plankton at Naples from March 1956 to August 1957 the following observations on occurrence of Gymnodinium breve in certain temperature and salinity ranges are of interest:

	Temperature ranges (^{o}C.)		
	17.0-23.5	23.6-28.4	28.5-31.9
Total numbers of samples	126	120	125
Samples with G. breve	3	9	5

	Salinity ranges (p.p.t.)		
	32.4-36.0	36.1-36.9	37.0-38.6
Total numbers of samples	126	121	115
Samples with G. breve	9	4	1

DRAGOVICH, ALEXANDER, JOHN H. FINUCANE, and BILLIE Z. MAY.
1961. Counts of red tide organisms, Gymnodinium breve, and associated oceanographic data from Florida west coast, 1957-59. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 369, iii + 175 p.

This report continues the presentation of original data (see Finucane and Dragovich, 1959) on red tide and associated ecological conditions. It covers the period from July 1957 through December 1959 and the area from Anclote Keys to Cape Sable.

DRAGOVICH, ALEXANDER, JOHN H. FINUCANE, JOHN A. KELLY, JR., and BILLIE Z. MAY.
1963. Counts of red-tide organisms, Gymnodinium breve, and associated oceanographic data from Florida west coast, 1960-61. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 455, iii + 40 p.

This paper continues the presentation of original data on red tide and associated oceanographic data from the west coast of Florida (see Finucane and Dragovich, 1959, and Dragovich, Finucane, and May, 1961). This report, however, includes observations on ammonia, total and inorganic nitrogen, silicon, calcium, and alkalinity.

DRAGOVICH, ALEXANDER, and JOHN A. KELLY, JR.
1964. A collection of data in reference to red tide outbreaks during 1963. 2. Preliminary observations on phytoplankton and hydrology in Tampa Bay and the immediately adjacent offshore waters. Fla. Bd. Conserv., Mar. Lab., p. 4-22.

From January to May, 1963, gives temperature, salinity, oxygen, inorganic phosphate-phosphorus, chlorophyll A, and monthly precipitation. Eight stations were occupied monthly. Blooms in April of Gymnodinium breve coincided with blooms of Ceratium furca, Prorocentrum micans, Gonyaulax diegensis (?) Rhizosolenia stolterfothi, and Tintinnidae. The red tide coincided with an intrusion into Tampa Bay of offshore water at a period of exceptionally low rainfall.

DRAGOVICH, ALEXANDER, and BILLIE Z. MAY.
1961. Hydrology of Tampa Bay and adjacent waters. In Galveston Biological Laboratory fishery research for the year ending June 30, 1961, p. 65-67. U.S. Fish Wildl. Serv., Circ. 129.

"...The distribution of G. breve seems to be restricted by temperature minima rather than maxima. G. breve was absent at temperatures below 14.2° C. which occurred in December and present at 31.3° C. in July.

"G. breve was absent from Tampa Bay during the months with lowest temperatures. The organism's simultaneous presence in the farther offshore waters continues to suggest that the warmer neritic waters may be important to the winter survival of G. breve.

"...During most of the year precipitation was below normal or near to the long-term means. Extremely heavy rainfalls were associated with hurricane 'Brenda' (July 28 and 29). According to the reported rainfall, hurricane 'Donna' (September 9-11), which swept through the general Tampa Bay drainage basin, was not a particularly wet hurricane...." [p. 65.]

DRAGOVICH, ALEXANDER, and BILLIE Z. MAY.
1962. Hydrological characteristics of Tampa Bay tributaries. U.S. Fish Wildl. Serv., Fish. Bull. 62:iv + p. 163-176.

Higher concentrations of total and inorganic phosphorus occurred in the Alafia, Little Manatee, and Manatee Rivers, which flow through a phosphatic district, than in the Hillsborough River. All of the rivers entering Tampa Bay have higher phosphorus than the Peace and Caloosahatchee Rivers.

"...Results of this investigation have shown that the average concentration of copper for all rivers combined is well below the toxic levels for G. breve...." [p. 175.]

DROOP, M. R.
1954. A note on the isolation of small marine algae and flagellates for pure cultures. J. Mar. Biol. Ass. U.K. 33(2): 511-514.

EICHER, GEORGE.
1947. Aniline dye in aquatic weed control. J. Wildl. Manage. 11(3):193-197. [See section of this report on control methods.]

ELDRED, BONNIE, KAREN STEINDINGER, and JEAN WILLIAMS.
1964. A collection of data in reference to red tide outbreaks during 1963. 3. Preliminary studies of the relation of Gymnodinium breve counts to shellfish toxicity. Fla. Bd. Conserv., Mar. Lab., p. 23-52.

Toxicity of oysters rose when red tide occurred in April to December, 1963 and decreased rapidly when red tide diminished.

ELDRED, BONNIE, VIOLET STEWART, LARRY GILLESPIE, JEAN WILLIAMS, and KAREN STEINDINGER.
1964. A collection of data in reference to red tide outbreaks during 1963. 4. Preliminary studies of vitamin B_{12}, carbohydrate, and phytoplankton in sea water. Fla. Bd. Conserv., Mar. Lab., p. 53-96.

Extensive tables for May to September, 1963, giving for several inshore and river mouth stations, vitamin B_{12} (assayed with Cyclotella nana), carbohydrates (method of Lewis and Rakestraw, 1955), phytoplankton counts by large groups, salinity, and temperature.

ENDLICH, F. M.
1882. An analysis of water destructive to fish in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4:124.

He reported upon two samples of sea water, one in which fish died and another in which they did not. He concluded that "I find that the water A [in which fish died] contains a large quantity of Algae and Infusoria. . . .

. . . . .

"In my estimation the death of fish was caused by the more or less parasitic alage, which are found in large quantities in water A, but do not occur at all in water B."

EWING, GIFFORD.

1950. Slicks, surface films and internal waves. J. Mar. Res. 9(3):161-187.

Explains the physical basis and biological significance of most slicks.

FEINSTEIN, ANITA.

1956. Correlations of various ambient phenomena with red tide outbreaks on the Florida west coast. Bull. Mar. Sci. Gulf Carib. 6(3):209-232.

The author calculated linear correlations between red tide outbreaks and rainfall, tropical disturbances, and stream discharge. In table 1 the author listed all years with red-tide outbreaks and ranked their intensity on a scale from 0 to 5 from 1844 to 1954. The data in the table are unavoidably subjective. The author, for instance, recorded a light outbreak in 1949 based on only one report of 3,000 dead fish (cause of death not certain) on Anna Maria Beach. Although 1887 is not listed in the table, the text mentions 1887 data from Harper (1927). For two of the years (1931 and 1936) the author gave as authority a personal communication (unidentified writer) to a member of the laboratory staff (also unidentified). This lack of adequate documentation, although not the fault of the author, is unfortunate.

The difficulty in measuring the abundance of the red tide organisms by reports of fish kills is probably so great that correlations with other phenomena are necessarily hard to detect.

FEINSTEIN, ANITA, A. RUSSEL CEURVELS, ROBERT F. HUTTON, and EDWARD SNOEK.

1955. Red tide outbreaks off the Florida west coast. Univ. Miami, Mar. Lab., Rep. 55-15 to Fla. State Bd. Conserv., p. 1-44.

The authors gave a chronological report on red-tide occurrence derived from many sources from 1844 to January 1955. Admitting that the data are subjective, the authors attempted to list the intensity of red-tide occurrences in categories of magnitude from 1 to 5 by calendar years.

In figure 1 they showed the occurrences by month from December 1953 to January 1955 by north to south areas. Their conclusion that the outbreaks "seem to move from south to north" does not appear to be justified by the evidence presented. The authors apparently recognized this weakness, stating that "Further data are required to give complete support to 2." [p. 1.]

In figure 3 they presented a histogram of the number of reported occurrences by month from 1878 to 1953, inclusive. The data give an incorrect impression, because the authors apparently listed the same months as many times as they ran across a report. The difference between their histogram and the tabulation we get for the same data for 1878-1954 is as follows:

	Jan.	Feb.	Mar.	Apr.	May	June
Report	9	0	0	2	1	3
Our tabulation	4	2	2	2	3	3

	July	Aug.	Sept.	Oct.	Nov.	Dec.
Report	18	24	15	17	21	12
Our tabulation	3	4	5	7	7	4

If each month in which red tide occurred is listed only once (our tabulation), it is obvious that there is not such a pronounced red-tide season as their report would indicate. Since the number of times the occurrence is recorded may, however, have a rough relation to intensity of the outbreaks, the true picture probably lies somewhere between these two curves.

Figure 4 and table 1 purport to show the relation of the dates of "apparent initial outbreaks of red tide" to the new moon in areas III, IV, and V. This tabulation is questionable because: 1) The boundaries of the "areas" are poorly chosen; the northern boundary of their area III bisects the mouth of Tampa Bay and the southern boundary of their Area V bisects Boca Grande Pass. 2) The dates on which newspapers took note of an outbreak do not mean that the outbreak started then. 3) The authors accepted some reports as "initial" outbreaks, but ignored other reports (presumably because they were not "initial" outbreaks) without any clue as to how they made their decision.

FINUCANE, JOHN H.

1958. Occurrence of red tide organisms. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958. U.S. Fish Wildl. Serv., p. 68-69.

". . . Concentrations of the organism in fish-killing density have, so far, been

found mainly in the neritic areas adjacent to major river drainages. The slope of the West Coast Florida continental shelf is very gentle, so that a depth of 60 feet lies 25-45 miles offshore; consequently, the neritic zone is broad.

"During periods of relatively light concentrations, tremendously dense sampling is necessary to validate the presence of the organism. For example, on two different occasions, samples taken every hour in the same water mass for periods of twenty-four hours showed the organism present in but 3 out of 50 samples in one instance, and in but 2 out of 48 in the other. Even during periods of heavy concentrations associated with fish kills, when samples were in an area of dying fishes, the counts varied from 0 to over 1 million per quart, further indicating the extreme patchiness of the organism's distribution in sea water."

Two series of hourly samples taken over 24-hour periods tend to show that the organism appears to concentrate at the surface during daylight and to move downward at night.

FINUCANE, JOHN H.
1959a. Field ecology relating to red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 76-79. U.S. Fish Wildl. Serv., Circ. 62.

"Since October, 1958, the dominant phytoplankton associated with G. breve in the water samples were recorded qualitatively in the inshore and offshore waters of Tampa Bay. Quantitative counts (commenced in January 1959) of dinoflagellates, diatoms and algae, made from preserved organisms stained on millipore filter paper, will be used to supplement these qualitative data." [p. 79.]

FINUCANE, JOHN H.
1959b. Fixing and staining of dinoflagellates. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 108. U.S. Fish Wildl. Serv., Circ. 62.

"Due to the extreme fragility of living G. breve, we are experimenting on techniques for the preservation of plankton samples in the field which will permit more precise quantitative and qualitative analyses of samples.

"Field samples were fixed immediately after collection with 0.5 ml. of 2 percent osmic acid in 1 percent chromic acid solution per 50 ml. of the sample. So far this fixative has been the most effective in preserving G. breve and other phytoplankton.

"Fixed water samples were stored under refrigeration at 36° F. These samples were later filtered under reduced pressure, using HA gridded millipore filters. After serial washes and the application of a mordanting solution, the organisms were stained on the millipore filter pad. The 3 most promising stains have been 1 percent Fast Green FCF, 1/2 percent Gentian Violet, and 1/2 percent Crystal Violet. These filters are first cleared in cedar oil or Cargille oil, then cut in half, and mounted with balsam or Permount on a glass slide. A permanent slide index of the phytoplankton taken since January 1959 at selected stations is being maintained. There is some tendency for G. breve cells to round up during filtration, but no distortion or cytolysis of armored dinoflagellates or diatoms was noted.

"This technique can be used to supplement living counts of G. breve and associated phytoplankton and may be valuable during extended offshore sampling trips when large changes in the number of organisms could occur before examination of the samples."

FINUCANE, JOHN H.
1960. Field ecology relating to red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 52-54. U.S. Fish Wildl. Serv., Circ. 92.

"The 1959 red tide outbreak started during the last part of September and continued through November. The initial pattern of distribution was similar to the 1957 outbreak with blooms of G. breve first occurring outside the islands. The first fish kill was reported September 29, offshore from St. Petersburg Beach. The greatest observed numbers of G. breve (480,000-1,330,000 per liter) were found in the neritic waters 3-10 miles west of Egmont Key, September 30. By October there was a rapid decline in both numbers and incidence of G. breve, 10-40 miles west of Egmont Key. This was particularly noticeable at stations 10 miles offshore where the numbers dropped from 1,120,000 per liter in September to less than 100 per liter during October. The coastal waters north of Egmont Key to Clearwater had a high count of only 33,000 per liter as compared to 540,000 per liter at the stations south of Egmont Key to Venice

the same month. The last recorded fish kill during this outbreak occurred October 22, 1959, 3 miles west of Egmont Key. [p. 52.]

"The incidence of G. breve decreased in Tampa Bay and the nearshore waters during November, but blooms of this organism to 400,000 per liter still occurred 10 miles west of Egmont Key. Following the advent of weather fronts accompanied by lower water temperatures and turbulent sea conditions, G. breve incidence and numbers declined during December 1959 and January 1960.

"From February to April 1960 G. breve increased again in numbers and distribution. In March, 35 miles west of Egmont Key, a bloom of 6,320,000 per liter was observed. Scattered dead fish extended 15-35 miles offshore. No further fish kills were reported in April and May. The highest population encountered at that time was 21,000 per liter 10 miles west of Egmont Key.

. . . . .

"The neritic nature of G. breve was indicated by its presence to depths of 123 feet in numbers ranging from 7,000-16,100 per liter, 40 miles west of Egmont Key, November 1959 and March 1960.

"Organisms were present in the nearshore and offshore waters throughout the year during non-bloom periods.... G. breve was completely absent from the middle of Tampa Bay except during the blooms of September-October 1959 and February-March 1960. This suggests that G. breve is primarily a neritic organism found in estuarine waters only when special conditions exist.

"Organisms were generally present in lower than normal salinities, ranging from approximately 30-35‰ during blooms. Waters having values less than 24‰ did not contain blooms of G. breve in Tampa Bay. While salinity may have served as a barrier for G. breve in estuarine waters, it does not normally seem to be a limiting factor in neritic waters.

"Water temperatures above 22° C. seem to be favorable for blooms of G. breve with the optimum around 26°-28° C. However, during February and March 1960, dense populations of G. breve developed at temperatures between 15°-18° C. Since G. breve has been observed in waters as cold as 9° C., low water temperatures normally may not be an absolute limiting factor for the existence of this organism. Temperatures below 14° C. and above 30° C. may inhibit blooms. [p. 53.]

. . . . .

"Blooms of Prorocentrum micans and Ceratium furca occurred during November and December 1959 in Tampa Bay. . . blooms of Gymnodinium splendens were present March 29, 1960, in upper and middle Tampa Bay. . . .

"Skujaella erythraeum continued to be the dominant blue-green alga in the surface waters from Tampa Bay to 40 miles west of Egmont Key during the summer and fall of 1959." [p. 54.]

FINUCANE, JOHN H.

1961. Ecology of red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1961, p. 61-64. U.S. Fish Wildl. Serv., Circ. 129.

"A minor red tide developed in the neritic waters off Tampa Bay during July and August 1960. Blooms of G. breve as dense as 420,000 per liter were found off Egmont Key, July 27, 1960. Fish kills, principally confined to that area, were of a very limited nature. During August the greatest numbers of this organism (up to 150,000 per liter) were present from 5 to 20 miles off Egmont Key. The number of samples containing G. breve increased from a low of 3 percent in June to 64 percent in August during this outbreak. No further fish kills were recorded after the first week in August. . . ." [p. 61.]

FINUCANE, JOHN H.

1964. Distribution and seasonal occurrence of Gymnodinium breve on the west coast of Florida, 1954-57. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 487, iv + 14 p.

"The term 'bloom' represents any concentration of G. breve exceeding the normal population level of approximately 1,000/1. G. breve counts of more than 250,000/1. were considered lethal during red-tide fish kills." [p. 1.]

The coast from Tarpon Springs to Cape Sable is divided into 3 sectors. Tables and figures give the relative abundance of G. breve in the samples by sector by 2-month periods from January 1954 through December 1957.

In sector A (Anclote Keys to Venice) the organisms were just approaching bloom abundance during 1954, scarce through 1955 and 1956, and in full bloom during the last 4 months of 1957.

In sector B (Venice almost to Naples) the organisms approached bloom during the first half of 1954 and bloomed from July 1954 through February 1955, then remained scarce until they bloomed again during the last 4 months of 1957. In sector C the organisms showed a sudden increase to just below bloom level from March through June 1954, and then commenced blooming and continued through February 1955. Bloom occurred again during the last 4 months of 1957.

In more than 9,000 samples, *G. breve* was not found in salinities below 21 or over 39 p.p.t., or at temperatures below 10^{o} or above 34^{o} C.

In simultaneous surface and bottom samples *G. breve* was higher in the surface samples. The great majority of the samples were collected, however, between 8 a.m. and 5 p.m.

". . . Since its incidence during non-bloom periods is primarily confined to offshore waters, the organism probably is more neritic than estuarine. *G. breve* occurred in approximately equal frequency in both estuarine and neritic waters only during the red-tide outbreaks in 1954 and 1957. The offshore distribution usually extended 6-10 miles, although in March 1960 a bloom of 6,320,000/l. was detected 35 miles offshore (Hutton, 1960). During the red-tide outbreak of 1954, Lackey and Hynes (1955) reported *G. breve* in samples collected 140 miles southwest of Fort Myers, Fla. . . ." [p. 8.]

FINUCANE, JOHN H., and ALEXANDER DRAGOVICH.
1959. Counts of red tide organisms, *Gymnodinium breve*, and associated oceanographic data from Florida west coast, 1954-57. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 289, iv + 220 p.

This report contains the original data on counts of the red-tide organism, *G. breve*, and concomitant physical and chemical hydrographic data collected from February 1954 through June 1957, between Clearwater and Marathon Key on the west coast of Florida. Hydrographic data include temperature, salinity, pH, copper, inorganic and total phosphorus, nitrate-nitrite, and carbohydrate and protein equivalents.

FINUCANE, JOHN H., GORDON R. RINCKEY, and CARL H. SALOMAN.
1964. A collection of data in reference to red tide outbreaks during 1963. 5. Mass mortality of marine animals during the April 1963 red tide outbreak in Tampa Bay, Florida. Fla. Bd. Conserv., Mar. Lab., p. 97-107.

Lethal concentrations of *G. breve* occurred for about 2 weeks, April 3-16, 1963, in an area from the mouth to about 25 miles inside Tampa Bay. No blooms were detected in upper Hillsborough Bay or Old Tampa Bay. Fifty-six species of fish were killed, also blue crabs, horseshoe crabs, and lancelets, but dead shrimp were not seen. The authors studied seine and trawl hauls made in the area in 1962 and 1963 and concluded that the effects of red tide on fish populations appear to be rather limited.

FISH, CHARLES J., and MARY CURTIS COBB.
1954. Noxious marine animals of the central and western Pacific Ocean. Fish Wildl. Serv., Res. Rep. 36:iii + 45 p.

Includes a few references on red tide.

FISHER, A.
1956. The effect of copper-sulphate on some microorganisms in fish ponds. Bamidgeh, Bull. Fish Cult. Israel 8(2):21-27.

Daphnia and *Cyclops* were not harmed by 1 mg./l. of copper sulphate; at 10 mg./l. *Daphnia* lived 35 hours. *Cyclops* was less affected than *Daphnia*.

FLORIDA STATE BOARD OF CONSERVATION.
1959. Red tide. Fla. State Bd. Conserv., 13th Bien. Rep. 1957-1958, p. 11.

A general account of efforts to control the 1957 red-tide outbreak.

FORTI, A.
1933. Il fenomeno de "lago di sangue" nello stagno di Pergusa in Sicilia alla metà di Settembre 1932. Nuovo Giorn. Bot. Ital. 40(1):76-78.

FRITSCH, F. E.
1935. The structure and reproduction of the algae. Vol. I. Univ. Press, Cambridge, 791 p.

Contains 176 references on Dinophyceae.

GALTSOFF, PAUL S.
1948. Red tide. Progress report on the investigations of the cause of the mortality of fish along the west coast of

Florida conducted by the U.S. Fish and Wildlife Service and cooperating organizations. Fish Wildl. Serv., Spec. Sci. Rep. 46, i + 44 p.

During the 1946-47 outbreak: All kinds of animals perished in the red water, including a small number of turtles and porpoises. Windrows of dead fishes piled on beaches comprised a great variety of common commercial and noncommercial varieties. Likewise, the pelagic and bottom invertebrates succumbed to the unknown poison. Large numbers of shrimp were seen dead, as well as common blue crabs, fiddler and mud crabs, barnacles, oysters and coquinas. Observations made by the author in March 1947, around the Fort Myers area, disclosed that about 80 percent of the oysters, Ostrea virginica, grown on piles, were dead.

"No mortality was observed among the hard shell clams, Venus mercenaria, and no reports were received of the destruction of ducks, gulls, and other birds inhabiting the inshore waters. Later during the summer information was received from residents of Largo, Florida, that 'thousands of sea gulls and pelicans died from eating the fish poisoned by the red tide.' The correctness of this observation has not been verified by the author." [p. 10-11.]

In June 1947, W. W. Anderson reported the species killed in the Fort Myers area to be 50 percent catfish; also included were pinfish, porgies, white trout and spotted trout, cowfish, spiny box fish, moonfish, spot, mullet, eel, sand-bream, whiting, thread herring, hogchoker, tongue fish, yellowtail, tripletail, redfish, and drum. Also very noticeable were carcasses of horseshoe crabs.

"... Sponge divers working last winter off Marco, Florida, reported that the bottom was littered with dead mackerel, although rarely were these fish found on the beaches. [p. 13.]

"Although few dead crabs were observed by Anderson, this may be due to the fact that these animals tend to sink upon death and would, therefore, be less noticeable. On the other hand, he frequently observed small species of crabs swimming in the infected waters in apparently good condition. On several occasions crabs were observed feeding on dead fish at the surface. He thinks that it is entirely possible that these crustaceans were less affected by the red water than were the fish. Horseshoe crabs (Limulus polyphemus), however, suffered a heavy mortality and thousands were washed onto the beaches . . . . [p. 13-14.]

. . . . .

". . . the water had an oily appearance. When dipped up and allowed to stand for 5 to 10 minutes, it became thick, sometimes almost of a consistency of Karo syrup, and slimy to the touch. . . . [p. 15.]

. . . . .

". . . Counts made by Woodcock and Anderson in the field show that the number of Gymnodinium in the surface layer of red water varied at this time from 13,000,000 to 56,000,000 per liter. Samples collected by plankton net contained also large numbers of Evadne. The intestines of this Cladoceran were stained deep red by ingested Gymnodinia. . . ." [p. 19.]

. . . . .

". . . Dinoflagellates, like other Protozoa, are very sensitive to copper sulphate and hypochlorite. Kofoid and Swezey (1921) state that copper sulphate in a concentration of 1 part per million killed all Ceratium hirundinella. This method was used by the Japanese biologists in their attempts to control the red water in the Gokasho Bay and in the Gulf of Konsa. Miyajima (1934) states that all dinoflagellates are instantly killed by a copper sulphate solution in the concentration of 2 parts per million. The concentration of 1 part per million kills them within a few minutes. In practice the copper sulphate was applied by attaching bags filled with this salt to the sides of motor launches which were run back and forth in the bay. After the treatment large numbers of destroyed dinoflagellates were found floating in the water. [p. 34.]

"To prevent the growth of bacteria which may develop after the destruction of dinoflagellates, the Japanese biologists suggest the use of 10 percent solution of calcium hypochlorite or the addition of liquid chlorine. Both solutions can be used simultaneously and their effective concentrations, according to Kominarui (quoted from Miyajima) should be adjusted to the salinity and temperature of the water. He states that at 13.6° C. ordinary bleaching powder containing from 34 to 35 percent of free

chlorine is effective in killing dinoflagellates at the concentration of 1:500,000. At 10° C. the concentration should be increased to 1:400,000. In combination with copper sulphate the concentration of hypochlorite can be reduced to 1 part per million. It is interesting to note that after the red water was destroyed by chemical treatment the Japanese biologists noticed the appearance of another dinoflagellate of the genus *Polykrikos* which apparently was harmless to pearl oysters.

". . . it appears promising to try the spraying of red water from aeroplanes or from boats with a solution of copper sulphate or dusting it with powdered calcium hypochlorite. Other chemicals, harmless to fish and shellfish, may be tried. The use of powdered calcium oxide (unslackened lime) suggested itself, for its addition to sea water will raise the pH to a level which is beyond the tolerance of the dinoflagellate and, at the same time, it is unlikely that the increased concentration of Ca salts in the water will adversely affect fish or shellfish, for the excess of Ca in sea water will be rapidly precipitated.

"Advantage may be taken of the fact that the greatest concentrations of dinoflagellates appear in patches which are, probably, the centers of their more rapid propagation. . . ." [p. 34-35.]

GALTSOFF, PAUL S.
1949. The mystery of the red tide. Sci. Mon. 68 (2):108-117.

Semipopular account of information given in his 1948 report.

GATES, JEAN.
1958. Toxicity of *Gonyaulax monilata* to fish. *In* Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 90-93.

This material was published by Gates and Wilson (1960).

GATES, JEAN A., and WILLIAM B. WILSON.
1960. The toxicity of *Gonyaulax monilata* Howell to *Mugil cephalus*. Limnol. Oceanogr. 5(2):171-174.

Gonyaulax monilata caused yearly summer mortality in Offatts Bayou from 1936-1941 (Gunter, 1942). Connell and Cross (1950) reported mortality "almost every year" for 15-20 years prior to 1949.

Gonyaulax killed fish at concentrations of 1,400 per liter. The fish lost equilibrium, then slowed their opercular movements.

GILSON, H. CARY.
1937. The nitrogen cycle. John Murray Exped., 1933-34. 2(2):21-81. [Cited from Ryther, 1955.]

GLAZIER, W. C. W.
1882. On the destruction of fish by polluted waters in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4:126-127.

Fish in live wells of fishing smacks have often died when passing through poisoned water, notably about 1865 and in 1878, when large numbers were thrown on the shore at Key West.

He reported (writing on November 25, 1880) that the waters of Tampa, Sarasota, and Charlotte Harbor were covered with thousands of dead fish, and several smacks lost their cargoes in the last 2 weeks.

GLENNAN, A. H.
1887. 4.--Fish killed by poisonous water. U.S. Fish Comm., Bull. 6:10-11.

Writing on October 28, 1885, Glennan stated that large shoals of dead fish were seen between Egmont Key Light and Charlotte Harbor. He reported that a fishing schooner a few weeks earlier had lost two loads of live fish in sailing through strips of this poisoned water.

GOODELL, H. G., and D. S. GORSLINE.
1961. Data report - the hydrography of Apalachicola and Florida Bays, Florida. Fla. State Univ., Sedimentological Res. Lab., Contr. 1:1-316.

GRAHAM, HERBERT W.
1942. Studies in the morphology, taxonomy, and ecology of the Peridiniales. Carnegie Inst., Wash., Publ. 542, 129 p.

GRAHAM, HERBERT W.
1954. Dinoflagellates of the Gulf of Mexico. *In* Paul S. Galtsoff (coordinator), Gulf of Mexico: its origin, waters, and marine life, p. 223-226. Fish Wildl. Serv., Fish. Bull. 55.

"Toxic red water such as occurs regularly in the pearl oyster beds in Japan (Mitsukuri 1904) could be disastrous to the vast oyster industry in the Gulf, but apparently the Gulf oysters have been spared any such visitation so far.

"Reports of red water on Campeche Banks, off Yucatán, are made occasionally by fishermen in that area, but to date it has not been possible to ascertain the causative agent. . . ." [p. 225.]

GRAHAM, HERBERT W., JOHN M. AMISON, and KENNETH T. MARVIN.

1954. Phosphorus content of waters along the west coast of Florida. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 122, v + 43 p.

Total, inorganic, and organic phosphorus was determined for waters of the Peace and Caloosahatchee Rivers, Charlotte Harbor, and 10 stations in the Gulf of Mexico off the west coast of Florida extending to 120 miles offshore. The period covered was May 1949 to January 1951, inclusive. Water samples were also analyzed for salinity, oxygen, and pH. This report contains only the phosphorus data; the remainder were published by Marvin (1955).

The authors stated, "No high degree of accuracy is claimed for the analyses of the river water, especially at Station 2 (Peace River). Concentrations there were frequently so high that dilutions with salt solutions were necessary. Furthermore, yellowish or greenish tints often developed in the samples so that addition of dyestuffs to the standards was necessary in order to effect a match in color.

"In an effort to clarify the water, some river samples were centrifuged. It was found that not only the total, but also the inorganic phosphorus was less in these samples, indicating that some of the inorganic phosphorus occurs in particulate form. . . ." [p. 2.]

The authors pointed out the possible role of *Skujaella* (*Trichodesmium*) in concentrating phosphorus. ". . . This filamentous blue-green alga is always present in the plankton there and frequently occurs in bloom proportions. It grows in the water and on the surface. . . . Its propensity for floating on the surface is the feature which is of importance to the present problem. . . .

"Since it accumulates at the surface it is driven by the wind. Sometimes it piles up in such abundance as to create a nuisance at bathing beaches. . . ." [p. 40.]

In four samples of water containing blooms of *Skujaella*, the inorganic phosphorus ranged from 0.05 to .20 ug.at./l., and the total phosphorus from 1.75 to 10.20 ug.at./l. A filtered portion of the sample with 10.20 ug.at./l. showed only 2.35 ug.at./l. of total phosphorus and only 0.05 of inorganic phosphorus. These analyses indicated that the alga can grow well in water containing scarcely measurable inorganic phosphorus and accumulate a high quantity of phosphorus and that high values of phosphorus in unfiltered samples of water containing red tide may have little bearing on the need for any specific amount for a bloom.

The authors observed *Skujaella* floating in bands several hundred yards wide and miles long. They speculated that if conditions at any time suddenly became unfavorable for *Skujaella* a great mass of organic matter would become available to decompose and release large quantities of nutrients that might cause blooms of other organisms.

Their data show that the phosphorus-rich waters of the Peace River do not normally increase the phosphorus content of local Gulf water to any measurable degree. The phosphorus in the surface waters of the Gulf gradually decreases out to a distance of about 85 miles.

Phosphorus found in larger quantities at depths below 50 m. was largely inorganic. Limited upwelling of deep water at certain times had no apparent effect on the phosphorus content of water in the euphotic zone.

There was no evidence that bottom sediments contributed appreciable quantities of phosphorus to Gulf waters.

GRAHAM, HERBERT W., and NATALIA BRONIKOVSKY.

1944. The genus *Ceratium* in the Pacific and North Atlantic Oceans. Carnegie Inst., Wash., Publ. 565, 209 p.

Mentions the tendency toward a higher number of species in areas lower in phosphates.

GRAN, H. H.

1929. Investigation of the production of plankton outside the Romsdalsfjord 1926-1927, 112 p. Cons. Perma. Int. Explor. Mer, Rapp. Proc.-Verb. Réun. 56. [Cited from Ryther, 1955.]

GULF COAST SHELLFISH SANITATION RESEARCH CENTER.

1964. Adverse chemicals and toxins in the marine environment and shellfish. U.S. Public Health Service, Shellfish Sanit. Res. Planning Conf. Feb. 25-26, 1964. Dauphin Island, Ala., 9 p.

In December 1962 several illnesses reported to the Sarasota County Board of Health were thought to have been

caused by eating shellfish. The Florida State Board of Health made bioassays for toxicity on shellfish samples for several southwest coastal counties. Since May 1963 the Florida State Board of Conservation has been identifying and counting phytoplankton in water samples collected from the same areas as the shellfish samples.

Since May 1963 the U.S. Public Health Service Laboratory (Dauphin Island) has been collecting shellfish samples from the St. Petersburg-Sarasota area for bioassay of toxicity. Since September 1963 regular shellfish samples have been taken in Lemon Bay.

"From the beginning many workers have considered that shellfish toxicity was casually [sic] related to the occurrence of Red Tide. The work so far has shown no results that are contradictory to this relation. In fact, many of the results suggest that the relation is true. However, rigorous proof of the Red Tide organism as the cause of shellfish toxicity remains to be demonstrated." [p. 7.]

GUNTER, GORDON.
1947. Catastrophism in the sea and its paleontological significance, with special reference to the Gulf of Mexico. Amer. J. Sci. 245(11):669-676.

". . . In connection with a heavy fish mortality on the Texas Coast, Lund (1936) called attention to the possible similarity of the case of Jordan's (1921) description of 'A Miocene Catastrophe.' . . . [p. 669-670.]

. . . . .

"Mass mortalities of marine animals on the west Florida Coast have been reported by Pierce (1883), Taylor (1917) and Gunter, Williams, Davis and Smith (1947). According to Taylor (1917) this phenomenon has been reported since 1844. It came again in 1946 and 1947. It has appeared on the average of 10.4 years since 1844 with skips ranging from one to thirty years. Occurrences in consecutive years such as 1883-84 and 1946-47, are continuations of the same outbreak. . . ." [p. 673.]

GUNTER, GORDON.
1949. The "red tide" and the Florida fisheries. Proc. Gulf Carib. Fish. Inst., Inaugural Sess.:31-32.

GUNTER, GORDON.
1952. The import of catastrophic mortalities for marine fisheries along the Texas coast. J. Wildl. Manage. 16(1):63-69.

"In the summer of 1935 a very heavy mortality of marine fishes and other animals occurred in the Gulf of Mexico and extended for a distance of 250 miles from the Rio Grande northward. A few fishes were killed in the lower bays but practically all of the mortality was confined to the Gulf. The amount of destruction was undetermined, but it was certainly enormous and ran into many million pounds. Since that time there was one other occurrence of this phenomenon in the fall of 1948. It occurred along the southern tip of the coast and was more localized. . . ." [p. 65.]

GUNTER, GORDON, F. G. WALTON SMITH, and ROBERT H. WILLIAMS.
1947. Mass mortality of marine animals on the lower west coast of Florida, November 1946-January 1947. Science 105(2723):256-257.

Dead fish were reported from Dry Tortugas to Boca Grande (130 miles). At Fort Myers dead fish exceeded 170 per foot of shoreline on January 19. Total number of dead fish was estimated at 50 million. Also killed were oysters, clams, crabs, shrimp, barnacles, and coquinas. The clam industry at Marco, 50 miles south of Fort Myers was not involved. Despite an isolated report of dead fish from a vessel passing Dry Tortugas, mortality did not appear to reach the Keys. A patch of vivid yellow water south of Useppa Island on January 28, consisted almost exclusively of Gymnodinium sp. with a mixture of numerous larval invertebrates. The water was viscid and slimy, having the consistency of diluted syrup. The oxygen was low, 33 percent saturated. Irritating gas from breaking surf occurred January 22-26 on Captiva Island.

GUNTER, GORDON, ROBERT H. WILLIAMS, CHARLES C. DAVIS, and F. G. WALTON SMITH.
1948. Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. Ecol. Monogr. 18(3):309-334.

The mortality was first noticed November 20, 1946, 14 miles offshore from Naples. It spread as far north as Boca Grande Pass. According to all reports, no mass mortality occurred north of Pine Island Sound. Mortality occurred southward definitely as far as Cape Romano. On January 19 the captain

of a small freighter reported dead fish from Dry Tortugas to Fort Myers. After the end of January 1947, no further reports were received of dead fish until April 2, when they were reported from Cape Florida to Marathon and west almost to Key West. Later fish mortality was reported south of the Keys in some places but apparently it had disappeared by the end of April. Total area covered by the outbreak was from Sarasota to the Florida Keys, and duration was from November 1946 to the latter half of August 1947.

Mortality occurred in turtles, bottlenose dolphin (Tursiops truncatus), Balanus, oysters, coquinas (Donax), Penaeus, crabs (Callinectes sapidus most common), and about 25 species of fishes.

The estimate of 50 million fish killed (Gunter, Smith, and Williams, 1947) was revised to 500 million. The number of dead fish averaged about one per square yard up to 4 or 5 miles offshore and about one per acre 10 miles offshore.

The average maximum air temperature at Fort Myers for the 4 months of October 1946 through January 1947 was abnormally warm--6.0° F. above the 55-year average. The hurricane of October 7, 1946, might also be implicated.

GUNTHER, E. R.
1936. A report on oceanographical investigations in the Peru coastal current. Discovery Rep. 13:107-276. [Cited from Pomeroy et al., 1946.]

Upwelling of water into photic zone is given as a source of nutrients.

HALE, FRANK E.
1950. The use of copper sulphate in control of microscopic organisms. Phelps Dodge Refining Corp., New York, 43 p.

HARRISON, EDWARD F.
1957. A study of the so-called red tide in the Gulf of Mexico. Privately printed, 6 p.

Suggests controlling red tide by dynamiting the mud lumps off the mouth of the Mississippi River and then violently agitating the water with water jets to liberate trapped gases.

HART, T. JOHN.
1934. Red "water-bloom" in South African seas. Nature 134(3386):459-460.

In mid-July 1934 a blood-red discoloration along several miles of the east coast of Cape Peninsula was caused by a ciliate he thought belonged to the genus Mesodinium.

HART, T. JOHN.
1942. Phytoplankton periodicity in Antarctic surface waters. Discovery Rep. 21:261-356.

HASLE, GRETHE RYTTER.
1950. Phototactic vertical migration in marine dinoflagellates. Oikos 2:162-175.

HASLE, GRETHE RYTTER.
1954. More on phototactic diurnal migration in marine dinoflagellates. Nytt Mag. Bot. 2:139-147. [Cited from Pomeroy et al., 1956.]

HAXO, F. T., and BEATRICE M. SWEENEY.
1955. Bioluminescence in Gonyaulax polyedra. In Frank H. Johnson (editor), The luminescence of biological systems, p. 415-420. Amer. Ass. Advance. Sci., Washington, D.C.

Gonyaulax polyedra may need other vitamins in addition to B_{12}, thiamine, and biotin.

HAYES, HELEN LANDAU, and THOMAS S. AUSTIN.
1951. The distribution of discolored sea water. Tex. J. Sci. 3(4):530-541.

Contains 225 references pertaining to the occurrence and causes of the overblooming of plankton, with special emphasis on dinoflagellates.

HELA, ILMO.
1955. Ecological observations on a locally limited red tide bloom. Bull. Mar. Sci. Gulf Carib. 5(4):269-291.

The study was made to determine the effect of passes in generating red-tide outbreaks. On p. 270 it is stated, "Thus it was possible to perform observations under the actual conditions of an initial Red Tide outbreak." The sampling was apparently done only from November 30 to December 2, 1954, however, and the outbreak was under way somewhat earlier. At their station B (Station B29 in Finucane and Dragovich, 1959) counts of G. breve were 30,000 per liter on November 24, and at their station X5, where they counted 60,000, the count on November 24 was 140,000.

The author attempted to explain the patchiness of G. breve concentrations by stating that the ebb tide flows westerly (actually southwesterly) down Boca Grande Channel, and suggested that the

flooding waters probably come from the region south of the Pass and cut off the ebbing waters. He stated, ". . . Thus this mechanism indicates how the coastal water patches may be formed in the narrow pass by the flood current completely cutting off each ebbing water movement." [p. 275.]

The author attempted to show these patches in figure 12 by imaging four successive patches of water in a row of eight G. breve observations extending altogether about 6 miles down Boca Grande Channel. In the face of the 2-knot currents he showed this conclusion to be unreasonable, as four patches would take four tidal cycles to form. Additionally, the slightly lower counts at his interpatch stations probably are not statistically significant.

We do not agree with the optimum salinity for G. breve suggested by the points plotted in figure 15. An attempt was made to prove vertical migration in G. breve; however, the data presented do not afford adequate proof.

HELA, ILMO, DONALD deSYLVA, and CLARENCE A. CARPENTER.

1955. Drift currents in the red tide area of the easternmost region of the Gulf of Mexico. Univ. Miami, Mar. Lab., Rep. to Fla. State Bd. Conserv. 55-11, 31 p.

During 1954 two driftcard operations were carried out off the west coast of Florida. The ultimate goal was to solve the problem of the peculiar nearshore movements of the floating dead fish.

"It was assumed that under the combined influence of the (1) more or less permanent ocean currents and of the (2) highly variable drift currents, produced locally by the winds, the paths of the driftcards would be roughly the same as the paths of the dead fish patches. In this report it is shown that the estimated path of the driftcards, and therefore the drift of dead fish patches, can for practical purposes be determined by means of the wind observations alone. . . ." [p. 1.]

On July 13, 1954, a total of 1,100 cards were dropped, 10 at each mile along four transects, 240° true, up to 30 miles offshore, between San Carlos Bay and Longboat Inlet. Another 1,000 cards were dropped in 18 passes, from Wiggins Pass north to Palma Sola. On November 17, 1954, 2,200 cards were dropped offshore by plane, in the same general area.

The authors stated the returns showed the existence of a permanent counterclockwise current eddy, the northern end of which seems to be at the latitude of Tampa Bay.

HIRASAKA, KYOSUKE.

1922. On a case of discolored sea-water. Annot. Zool. Jap. 10(15):161-164. [Cited from Martin and Nelson, 1929.]

According to Martin and Nelson (1929), Hirasaka stated red water caused by Gymnodinium sanguineum did no damage, but he cited an earlier outbreak that injured some fish, which he reported from Okamura; and also from Kofoid and Swezy (1921).

HOLLANDE, ANDRÉ, and MONIQUE ENJUMET.

1957. Sur une invasion des eaux du port d'Alger par Chattonella subsalsa (=Hornellia marina sub.) Biecheler. Remarques sur la toxicité de cette Chloromonadine. Bull. Sta. Aquic. Pêche Castiglione, n.s., 8(1965):273-280.

HORNELL, JAMES.

1917. A new protozoan cause of widespread mortality among marine fishes. Madras Fish. Dep., Bull. 11(2):53-66.

"Widespread fish mortality is a well known phenomenon on the Malabar and South Kanara coasts; its recurrence yearly along certain stretches of the coast line is regular, though its intensity varies within wide limits. . . .

. . . . .

". . . all Malabar fishermen whom I have questioned agree in saying that every year after the passing of the rainy season and the subsidence of the southwest monsoon, if there be a continuance of fine weather for a week or ten days, with plenty of sunshine, and a weak coastal current, the water inshore becomes turbid and discoloured, brownish or reddish in tint; that this water has such poisonous effects upon fish that large numbers become affected and eventually die. . . ." [p. 53.]

HORNELL, J., and M. R. NAYUDU.

1923. A contribution to the life history of the Indian sardine. Madras Fish. Dep., Bull. 17:129-97. [Cited by Ryther, 1955. Non vidi.]

Ryther stated the report described red water caused by peridineans occurring annually along the Malabar Coast, following the cessation of the southwest monsoon, diatom blooms, and heavy rainfall. Blooms occur during hot, calm weather in bands along the shore or in patches which move with the tide.

HOWELL, JOHN F.

1953. Gonyaulax monilata, sp. nov., the causative dinoflagellate of a red tide on the east coast of Florida in August-September, 1951. Trans. Amer. Microscop. Soc. 72(2):153-156.

Contains a description of Gonyaulax monilata. Author said that it killed fish, but no great quantity, in Indian River, Fla., during August 1951.

HUTCHINSON, G. EVELYN.

1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology 25(1):3-26. [Cited from Ryther, 1955.]

HUTNER, S. H., and JOHN J. A. McLAUGHLIN.

1958. Poisonous tides. Sci. Amer. 199(2): 92-96, 98.

A general discussion of red tides. Dinoflagellate toxins appear to block nerve impulses by preventing the production of acetylcholine, the substance which acts on the "end plate" of a muscle fiber to make the fiber contract. This is similar to the action of botulinum, the toxin of botulinus. No antidote to either poison has been found.

"The prospect for restraining blooms by removing essential nutrients from the water seems poor. Vitamin B-12, for example, could conceivably be cut down by dumping carboys of B-12-destroying bacteria in the water, but truly enormous quantities of bacteria would be required to make any impression on several hundred square miles of ocean. . . A more promising attack seems to be the encouragement of natural predators, the technique which has so often been successful with insect pests. Dinoflagellate blooms are often succeeded by blooms of creatures that prey on them, most conspicuously the ciliate protozoa and, in warm waters, the luminous, predatory dinoflagellate Noctiluca. . . . [p. 95.]

Because B-12 and the pseudo-B-12 vitamins are large molecules built around an atom of cobalt, they suggested there may be unproductive areas of the ocean caused by lack of cobalt, similar to areas on land known as "cobalt-deserts" where livestock die from lack of cobalt in the soil.

They stated that in fresh water the growth of Euglena is a sensitive indicator of the amount of B-12 present, but no similar organism has been discovered for use in salt water.

They showed a photomicrograph of Zooxanthellae, symbiotic algae that live in jellyfish and coral. When these simple round cells were grown in proper media, they developed into the dinoflagellate Gymnodinium adriaticum, mobile and with flagella.

HUTNER, S. H., L. PROVASOLI, ALBERT SCHATZ, and C. P. HASKINS.

1950. Some approaches to the study of the role of metals in the metabolism of microorganisms. Proc. Amer. Phil. Soc. 94(2):152-170.

HUTTON, ROBERT F.

1956. An annotated bibliography of red tides occurring in the marine waters of Florida. Quart. J. Fla. Acad. Sci. 19(2-3):124-146.

"At Ballast Point in Hillsborough Bay south of Tampa, Florida, a minor Red Tide occurred periodically during 1955. Fishes did not seem to be harmed as minnows (Gambusia) and mullet (Mugil) were seen swimming through the streaked areas from time to time. However, shrimp in bait-wells located on the fishing pier at Ballast Point died when this water was pumped into the wells although good water circulation was maintained. A dinoflagellate, Ceratium furca (Ehrenberg), was the predominant organism in the water examined and counts as high as 17,600,000 cells per liter were observed." [p. 125.]

The author stated that, "Lackey (1955) reported a bloom of the diatom Coscinodiscus in the area around the mouth of the Myakka River in 1953." [p. 125.] The indicated reference, however, is not listed.

The annotations are largely uncritical; they serve as a guide to contents and often consist of the author's own abstract.

HUTTON, ROBERT F.

1960. Notes on the causes of discolored water along the southwestern coast of Florida. Quart. J. Fla. Acad. Sci. 23(2): 163-164.

Discoloration can be caused not only by red tide but also by a blue-green alga, Skujaella (Trichodesmium) thiebauti De Toni, which causes discolorations frequently reported by boat captains and airplane pilots as red tide.

During 1960 discolorations had three causes:

1. Gymnodinium breve Davis. In January 1960, counts were as high as 7

million per liter between Cape Romano and Englewood. On March 23, counts were over 6 million per liter 15 to 35 miles west of Egmont Key.

2. Gymnodinium splendens Lebour. On March 27 several square miles were discolored south of Gandy Bridge in Tampa Bay with counts of more than 5 million per liter (no apparent damage to fish).

3. Acartia tonsa Dana and Labidocera aestiva Wheeler. These crustacea caused a streak of reddish brown water 1 1/2 miles west of Big Sarasota Pass on March 29. No dead fish were seen. Counts of A. tonsa were over 350,000 per liter, but L. aestiva was much less abundant.

ICHIYE, T.
1962. Circulation and water mass distribution in the Gulf of Mexico. Fla. State Univ., Oceanogr. Inst., Contr. 190, 76 p.

INGERSOLL, ERNEST.
1882. On the fish-mortality in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4:74-80.

He attempted to discover facts concerning fish kills that had occurred in 1880 and came up with the following information from talking with residents:

1) As far back as 1844 [in 1844?] a widespread destruction occurred.

2) This occurred again in 1854.

3) This has occurred at intervals since, to a less degree.

4) In 1878 an "excessive fatality" occurred, probably more destructive than the later visitation of 1880. He placed so much emphasis on the death of sponges in 1878 that one wonders whether the 1878 incident was red tide or a sponge disease.

5) Even the cooler half of 1879 was not exempt from some appearance of the plague.

6) The 1880 red tide appeared in August immediately following "the terrible hurricane which is known as the 'August Gale.'" Fish died along the southern shore of Tampa Bay and Egmont Key south to Shark River, south to Bahia Honda Passage, and beyond Key West.

7) At Egmont Key the first dead fish occurred on October 17, 1880, and the red tide was in full swing by October 25. Fish continued to die for 6 weeks, at a decreasing daily rate.

". . . there was immense quantities of fresh water coming down the bay, and the water here [Egmont Key] was nearly fresh on the surface, while the water underneath was perfectly salt. . . . it continued to blow from the south and west until the 11th of October. . . ." [p. 77.]

A report containing raw hydrographic data obtained in an area north of Key West from Cape Sable to Dry Tortugas (July-December, 1961).

INGLE, ROBERT M.
1954. Irritant gases associated with red tide. Univ. Miami, Mar. Lab., Spec. Serv. Bull. 9, 4 p.

Gives blooming of Gymnodinium brevis as the cause of irritant gases on beaches of Florida's west coast. The author said that gases are given off only if red-tide waters are heated or agitated. The theory is discounted that the poisonous gases bring about growth of G. brevis. Irritant effects are only temporary and "do not appear unless wind-driven waves with associated water vapor and droplets exist." [p. 1.]

INGLE, ROBERT M., and DONALD P. deSYLVA.
1955. The red tide. Fla. State Bd. Conserv., Educ. Ser. 1, 30 p. [Revision of 1948 edition.]

For general information of the public.

INGLE, R. M., R. F. HUTTON, H. E. SHAFER, JR., and R. GOSS.
1959. The airplane as an instrument in marine research. Part I. Dinoflagellate blooms. Fla. State Bd. Conserv., Spec. Sci. Rep. 3, 25 p.

The authors reported that semicircular surface structures were common features of the 1957 red-tide outbreak near the mouths of passes. "The muddy bay water . . . lay proximal to the pass. Dead fish were not abundant in the muddy less saline water. Typically, the interface between the water masses was filled with a line of dead fish. [p. 3.]

. . . . .

"In every case observed by the authors (R.M.I. and R.F.H.) the discolored water, denoting a high concentration of dinoflagellates, was found from the interface and extending seaward.

"Because of their role in concentrating nutrients and dinoflagellates, and due to their frequency of occurrence, interfaces may well serve to rejuvenate and sustain red tides once they begin. If this is true, control measures directed to the specific areas of junction of dissimilar water masses may serve a useful purpose." [p. 5.]

This report states that after October 15, 1957, spraying of copper sulfate crystals was discontinued and control measures consisted of suspending bags of copper sulfate off bridges, etc. in 27 passes between Clearwater and Naples.

INGLE, ROBERT M., and JAMES E. SYKES.
1964. A collection of data in reference to red tide outbreaks during 1963. 1. 1963 red tide and associated studies--a preliminary report. Introduction. Fla. Bd. Conserv., Mar. Lab., p. 2-3.

An introductory paper to several reports on an April 1963 outbreak of red tide in Tampa Bay.

JEFFERSON, J. P.
1879. On the mortality of fishes in the Gulf of Mexico in 1878. Proc. U.S. Nat. Mus. 1:363-364.

In his letter (written in December 1878) to Spencer F. Baird, he described a second occurrence (see Jefferson et al., 1879) of a large body of dark-colored water moving southward along the Florida coast, across Florida Bay, and striking the Tortugas about November 20, 1878 and extending up the reef as far as Key West, probably farther.

He mentioned that oysters in Tampa Bay were killed by the water. He also reported that in October the Caloosahatchee River overflowed its banks along its entire length, except at a bluff in Fort Myers.

JEFFERSON, J. P., JOSEPH Y. PORTER, and THOMAS MOORE.
1879. On the destruction of fish in the vicinity of the Tortugas during the months of September and October, 1878. Proc. U.S. Nat. Mus. 1:244-246.

". . . On the 9th instant [October 1878], the sailing-vessel which connects us with Key West met water of a dark color about midway between here [Dry Tortugas] and there, but saw no dead fish. On her return, on the night of the 11th, she struck it off Rebecca Shoals, about 25 miles east of here, and found it extending some 10 miles out in the Gulf. That same night it came down upon us here, and the next morning the beach and surface of the water, as far as the eye could reach, were covered with dead fish. . . . From the fact that almost all the fish that first came ashore were small and of such varieties as frequent shoal water, I infer that the dark water must have been of less density than the sea. . . . The destruction must have been very great, for here, on a key containing but a few acres, and with a very limited extent of beach, we have buried at least twenty cart-loads. . . ." [p. 244.]

The letters also alluded to fish dying in Florida Bay and to death of almost all the conchs around the Dry Tortugas.

JOUAN, H.
1875. Mélanges zoologiques. Mortalité sur les poissons à la côte de Malabar. Mem. Soc. Sci. Nat., Cherbourg 19:233-245.

JÜNGST, H.
1937. Fischsterben im Kurischen Haff. Geol. Meere Binnengewässer 1:352-354.

KAISER, E.
1930. Das Fischsterben in der Walfischbucht. Palaeobiologica 3:14-20.

KETCHUM, BOSTWICK H., and JEAN KEEN.
1948. Unusual phosphorus concentrations in the Florida "red tide" sea water. J. Mar. Res. 7(1):17-21.

Several sea water samples were taken in July and August 1947, preserved with chloroform, and shipped to Woods Hole for analysis. Their phosphorus values include the organic phosphorus combined in particulate matter and plankton, the organic phosphorus in solution, and inorganic phosphate-phosphorus.

High total phosphorus values were obtained in the samples containing heavy blooms of red tide. The only way the authors could account for the high concentration was by assuming that the organisms were able to accumulate the phosphorus from the entire water column.

KIERSTEAD, HENRY, and L. BASIL SLOBODKIN.
1953. The size of water masses containing plankton blooms. J. Mar. Res. 12(1):141-147.

"If a phytoplankton population is assumed to be increasing logarithmically in a mass of water surrounded by water which is unsuitable for the survival of the population, it can be shown that there is a minimum critical size for the water mass below which no increase in concentration of phytoplankton can occur. . . . [p. 141.]

. . . . .

"We conclude, therefore, that a population in a finite region can support

itself against diffusion only if its reproductive rate exceeds the leakage, which is of the order of magnitude of the ratio of the diffusivity to the square of the extent of the region in the direction of most rapid diffusion." [p. 146.]

KING, GLADYS S.
1950. Production of red tide in the laboratory. Gulf Carib. Fish. Inst., 2d Annu. Sess.: 107-109.

Specimens of Gymnodinium breve could not be obtained, but bacteria-free cultures were made of G. simplex and Plagicampa marina. Inorganic phosphates and nitrates had no growth-promoting effects. The organisms would grow in an entirely synthetic medium which contains artificial sea water and amino acids added as pure chemicals.

It was recommended that dissolved organic nitrogenous matter in Gulf water be investigated as a clue to blooms.

KING, JOSEPH E.
1950. A preliminary report on the plankton of the west coast of Florida. Quart. J. Fla. Acad. Sci. 12(2):109-137.

Describes, in general, plankton forms of the west coast of Florida, especially dinoflagellates. Samples were taken from January to October, 1949. Clarke-Bumpus plankton sampler was used for quantitative sampling. Seventy-five samples were collected, and listings of plankton taken were given. Although four species of Gymnodinium were listed, G. breve was not included, possibly because all samples were centrifuged at 2,000 r.p.m. for 5 minutes, which might destroy the fragile red-tide organism.

KOCZY, F. F., M.O. RINKEL, and S. J. NISKIN.
1960. The current patterns on the Tortugas shrimp grounds. Proc. Gulf Carib. Fish. Inst., 12th Annu. Sess.: 112-125.

A study to determine residual currents off the southern west coast of Florida.

KOFOID, CHARLES ATWOOD.
1911. Dinoflagellata of the San Diego region. IV. The genus Gonyaulax, with notes on its skeletal morphology and a discussion of its generic and specific characters. Univ. Calif. Publ. Zool. 8(4):187-287.

Reported great injury to benthic species by Gonyaulax polyedra. In some cases water discoloration extended for several miles. He also mentioned an outbreak of yellow water caused by Gymnodinium flavum and accompanied by great luminescence.

KOFOID, CHARLES ATWOOD, and OLIVE SWEZY.
1921. The free-living unarmored Dinoflagellata. Univ. Calif., Mem. 5:1-562.

Gymnodinium sanguineum was cited by Okamura as injuring fish in Japan.

LACKEY, JAMES B.
1956. Known geographic range of Gymnodinium brevis Davis. Quart. J. Fla. Acad. Sci. 19(1):71.

Reported obtaining Gymnodinium breve in two out of four water samples collected at Trinidad. The samples with G. breve were taken on March 30 and April 1, 1955, at a temperature of 69 to 70.5° F.

"According to commercial fishermen, there is a yearly fish kill about the first of the year, which is not always catastrophic, but might be due to brevis. So well-known is this that it has become the basis of a study of areal ocean currents as affected by meteorology and the flow of the Orinoco River, emptying its nutrient rich waters into the Gulf of Paria."

LACKEY, JAMES B.
1958. Effects of fertilization on receiving waters. Sewage Industr. Wastes 30(11):1411-1415. [Cited from Biol. Abstr.]

Adverse effects of fertilization of receiving waters by sewage or other sources are briefly reviewed. Toxic effects produced by algal blooms, such as the Florida red-tide Gymnodinium brevis and Prymnesium, which occur in stock-watering ponds, are mentioned. Adverse esthetic and physical effects of eutrophication in such locations as the Madison, Wis., lakes, and Lake Washington at Seattle, and interferences with treatment of the domestic water supply are cited. Extreme diurnal dissolved-oxygen fluctuation may also result from formation of algal blooms. Author concluded that adverse effects of admission of mineralized sewage treatment effluents to receiving water outweigh the possible benefits of stimulating growth of higher living forms.

LACKEY, JAMES B., and K. A. CLENDENNING.

1963. A possible fish-killing yellow tide in California waters. Quart. J. Fla. Acad. Sci. 26(3):263-268.

During the summer of 1961, Gymnodinium flavum, a pale yellow dinoflagellate about 40 microns in diameter, was abundant in San Diego waters, reaching a maximum of 1,776 per ml. in one sample. It is suspected of causing small fish kills in Mission Bay.

LACKEY, JAMES B., and JACQUELINE A. HYNES.

1955. The Florida Gulf coast red tide. Fla. Eng. Ind. Exp. Sta., Coll. Eng., Eng. Progr. Univ. Fla. (9(2):1-23), Bull. 70, 23 p.

The report contains a sketch of G. breve and the following description of the organism:

"The organism is somewhat discoid in outline, having a transverse groove or girdle, and an indentation or sulcus from this girdle to the posterior body edge, so the body is divided roughly into four quadrants on its ventral surface. At the upper end is a small protuberance or nipplelike projection. The sulcus actually extends to the apical end of this nipple, but this can usually be determined only with the oil immersion objective, at about 930x. There is no shell or armor as in some other dinoflagellates. The width is about 30 microns, and the length about 25. There are approximately 22 discoid chromatophores (chlorophyll-containing structures) which appear pale yellow-brown in transmitted light. Dense swarms of the organisms appear reddish-brown in reflected light. The nucleus is typically large and, as in all dinoflagellate nuclei, it shows closely packed threads in a spiral or parallel arrangement. This is so characteristic, and dinoflagellate nuclei are so resistant to disintegration, as to greatly facilitate identification. In the catenate (chain-forming) Cochlodinium, formalin used for preservation disrupts the cells, but the nuclei still stand out and remain connected by amorphous remains of the cells. Sometimes a few brevis are similarly disrupted, but the persistent nuclei and chromatophores are diagnostic. The cell contents are clear and finely granular, except that several round refractive bodies may be present. No ingested food has ever been seen, and the organism probably lives holophytically, i.e., like a green plant, although it is believed able to assimilate some dissolved organic matter. [p. 6.]

"The only observed method of reproduction is by binary fission. Under optimum conditions several divisions may occur in 24 hours, so that blooms are easily accounted for. In general, the behavior of this species corresponds to that of dinoflagellates as a whole, but its effects have made it infamous. [p. 6.]

. . . . .

"There have also been rumors of enteric troubles due to eating shellfish from a Red Tide infected area. This point of human illness is emphasized by La Cossitt (5) in a popular journal, but it should be stressed that there has been no definite tracing of any human illness to brevis, and there has been no widespread illness when the Tide was present. The county health officers of the affected area have reported no health troubles from it. Dr. Wright, of Sarasota County, personally obtained clams dug in a heavily infested area, and bacteriological examination of them by a trained shellfish bacteriologist showed nothing unusual. It should be pointed out that Hornell (loc. cit.) says the people along the Indian Malabar coast harvest and eat the fish killed by their Red Tide. No toxic effects like those due to Gonyaulax on the California coast have been demonstrated. Quite respectable strings of sheepshead and other fish have been caught in waters containing up to 100,000 brevis per liter. These were eaten with no untoward effects whatever. Nevertheless, publicity in newspapers and nationally circulated magazines concerning actual damage plus rumored effects has tended to magnify conditions and probably has further contributed to financial loss in the area." [p. 6.]

The authors said that estimates of fish kills are difficult. They believed that despite the numbers of dead fish observed, the percentage of kill was low. They stated, ". . . Schools of fingerlings have been observed in the very shallowest inshore waters where there was a heavy kill a few hundred yards away. The upper part of Tampa and Hillsborough bays was not invaded by the Tide in 1953-54, and at least some large fish were present there. It was also observed that while a bad outbreak with attendant fish mortality might be in progress at one point, a few miles away one would find sports fishing and bathing going on as usual, and no scarcity of mullet for cut bait. At the time

of writing, the last localized outbreaks of the 1953-54 Red Tide are only a few weeks past, yet sports fishing (grouper, speckled trout, mackerel, and redfish) has been generally good throughout the entire area . . . ." [p. 7.]

They gave the following table of fish kills:

COUNTS OF DEAD FISH

On Land

LONGBOAT KEY

September 18, 1953

Fish Counted in Quarter Mile

Yellow Tails	298	Speckled Trout	4
Whiting	11	Puffer	1
Jack Crevalle	2	Angel Fish	1
Redfish	3	Porcupine Fish	8
Pompano	1	Red Snapper	1
Eel	21	Shiner	2
Ladyfish	3	Horseshoe Crabs	2
Catfish	11	Unidentified Fish	33
Toadfish	6		
Triggerfish	2		421
Mullet	11		

SIESTA KEY

September 19, 1953

Fish Counted in 125 Paces (yds.)

Grouper	2	Catfish	4
Whiting	14	Flounder	1
Eel	3	Sheepshead	1
Porcupine Fish	8	Angel Fish	1
Mullet	14	Yellow Tails	200
Ladyfish	1		
Toadfish	7		256

VENICE JETTIES

September 19, 1953

Fish Counted in 100 Paces (yds.)

Mullet	418	Other Species	15

MIDNIGHT PASS

December 18, 1953

Fish Counted in Quarter Mile

About 1000 Sheepshead   About 8000 Other Species

At Sea

SOUTHWEST OF PASS-A-GRILLE, 10 MILES

September 18, 1953

Huge windrow here, but for several miles an average of 1 dead fish per 10 feet.

OFF SANIBEL LIGHT, 6 MILES

March 18, 1954

Dead fish averaged 1 per 15 feet for an area of several square miles--perhaps 5 x 5 miles.

"For purposes of future study, water samples containing G. brevis are preserved by adding 5 ml. of formalin per 100 ml. of sample. G. brevis then rounds up and becomes a flattened oval or circular disc, usually losing its two flagella. Color is ordinarily lost in a few days. Its chromatophores frequently assume a median bandlike position, and the girdle and sulcus become indistinct. The anterior nipple often can be distinguished. With very little practice the species is totally identifiable, even after the color has wholly disappeared from the chromatophores. [p. 8.]

"In the field, grab samples are taken in shallow water simply by lowering a container from a bridge, dock, or boat, and getting an approximate surface sample. For vertical sampling Foerst bottles are used, and the depth calculated roughly from meter markings on the line and the angle of the line. This is further correlated with the depth for the station as indicated by a Coast and Geodetic Survey map. [p. 8.]

"Preserved samples are sedimented in the dark for two weeks or more, when the supernatant may be siphoned off, and the catch concentrated by centrifuging the final 50 or 100 ml. for five minutes at about 2200 rpm in pointed-end 50 ml. tubes.

"Samples to be examined alive are protected from the sun and from any sudden increase in temperature. Such living samples should be concentrated and studied within eight or ten hours, also by centrifuging. No tendency to disintegrate has been observed at the speeds used (up to 2300 rpm.), but living organisms will cytolyze within 15 or 20 minutes under a cover glass. [p. 8.]

"Counting is done by a drop method. The catch is concentrated in ratios such that 6 drops of catch = 100 ml. of raw water. In dense blooms this ratio may be doubled or quadrupled, i.e., 12

or 24 drops = 100 ml. of raw water. One drop, therefore, equals 16, 8 or 4 ml. of raw water, approximately. A 25 mm. square No. 1 cover glass is used, and with the usual 10x oculars and 10x or 43x objectives in the microscope there are 16 or 64 paths--not circular fields, but paths--across such a cover; that is, in one drop of catch. If a drop of catch = 16 ml. of raw water, obviously one path at 100x (10x oculars and 10x objective) equals one ml. of raw water and at 430x one path equals 1/4 ml. Using the mechanical stage, one counts two paths across each drop on a slide, bisecting the cover and at right angles to each other. This usually compensates for inequality of distribution beneath the cover, and often enables one to identify much smaller organisms than can be identified in a counting chamber. The method is fast and easy, and the amount of error is small. The number of paths counted depends to some extent on the accuracy desired. Common practice has been to count eight paths (two paths for each of four drops), which at 430x usually equals two mls. of raw water. G. brevis is not always certainly identified at 100x, but is unmistakable at 430x. [p. 8.]

. . . . .

". . . The 1952 outbreak was apparently rather limited in the area affected, which seemed to center around Sanibel Island. There is little published information on this outbreak, at least at the present time. . . . [p. 11.]

"The first brevis to appear in 1953 were found in samples taken in Lemon Bay from the bridge on August 19, and in Sarasota Bay at the Cortez bridge, August 26. The first of these was a preserved sample, containing 116 brevis per ml. and the second a living sample, showing 178 per ml. On the latter date, August 26, there were no brevis at Naples or at Piney Point. On September 1 the organism appeared at the Placida Ferry wharf, and on September 3 there were 1,732 per ml. in Big Sarasota Bay, about three miles north of the bridge, and 600 per ml. in the surf at Golden Beach on Longboat Key. They were also present as far out as 22 miles off Anna Maria, and on this date dead fish were appearing. It is significant that no dead fish were seen, or at least reported, until after the populations of brevis had attained considerable numbers. [p. 11.]

"Such was the beginning of the 1953-54 Red Tide. From the very first it was marked by local concentrations rather than a widespread uniform distribution. The area covered was very large, and brevis was found in samples taken as far north as Tarpon Springs and as far south as Big Marco Pass, a distance of 175 miles, and from land-locked waters such as Lemon Bay to 45 miles offshore. A sample network for an area this size was not possible, despite the efforts of the three research organizations at work and those of the Gulf Coast Coordinating Committee. In the event of another outbreak, some such set-up to assess the magnitude of the invasion seems almost a necessity if distribution is to be ascertained. [p. 11.]

"At the north and south ends of the infested area there was a rather sharp tapering off of brevis populations. No fish kills were reported from Tarpon Springs or Big Marco Pass, although dead fish were reported as abundant off Anclote Key on at least two occasions. These may well have been carried there by the northbound current of the eddy reported by Hela (11). Out in the Gulf, the most westerly reported occurrences of brevis were about 140 miles southwest of Fort Myers in samples taken by the U.S. Coast and Geodetic Survey ship 'Hydrographer.' At the time of this writing some of the offshore Gulf samples are still awaiting analysis. However, the diminution in numbers along the western edge of the shaded area (Figure 1) indicates that the area of intense growth is fairly well delimited. [p. 11.]

"Clearwater had a single small fish kill along its beaches, with some attendant discomfort; Naples had a rather larger one. The beaches between these two points, from Fort Myers Beach to the Pinellas county beaches, all had one or more very heavy fish kills, and the inhabitants were subject to a great deal of discomfort. Probably the most continuously affected area was from Casey Key to Sanibel, and the heaviest continuous infestation was in the Boca Grande area. [p. 11-12.]

. . . . .

". . . one cannot detect a discoloration of the water at the surface until the number of brevis exceeds 250,000 or more per liter. . . .

"Frequently, samples taken a few miles from a rather dense local swarm will show no brevis at all. Examples of this are easy to cite. On September 18, 1953, samples taken just off Pass-a-Grille had 2,444,000 per liter, while there were none at John's Pass or in Sarasota Bay at Cortez. Samples at the latter station contained 83,200 per liter

three days later. The whole picture . . . is one of usually low or absent brevis populations during all of 1953-54, but with sudden erratic, scattered flare-ups to enormous numbers. . . . [p. 13.]

. . . . .

"Much attention has been directed toward recognition of red water from boats and planes . . . it is frequently possible to spot patches of bloom in this way. In Peconic Bay it has been possible to spot blood-red concentrations of a related dinoflagellate, Cochlodinium as far as a half-mile away from a small cabin cruiser. However, no such vivid discolorations have been noted in hunting for brevis either by boat or by air, and red water has frequently been all but impossible to locate, or has been a slightly brown discoloration rather than red. . . . any water located in such a manner must be examined microscopically. . . . [p. 13.]

. . . . .

". . . Considering the tendency of phytoplankton to accumulate in the topmost few inches in lakes, ponds and even streams as a direct response to light, it is evident that brevis presents no such clearcut response. . . . a trend to accumulate in deep water is sometimes evident and will be more closely investigated in future work. [p. 14-15.]

". . . Since much of our idea of the distribution of brevis has been based until now either on surface samples or (perhaps) on dead fish, these observations suggest that currently accepted distribution patterns, or areas of infestation, be accepted tentatively, for depths greater than ten feet. [p. 15.]

. . . . .

". . . In the light of past experiences with algicides, it seems probable that one of rather high specificity and very high killing power can be developed for brevis. . . . control of brevis in the shallow inshore areas along the coast by the use of plane-dispersed algicides must not be discounted, until very thoroughly evaluated. [p. 18.]

"Gymnodinium brevis requires small quantities of organic substances in its nutrition. Wilson (13), in his culture medium, includes vitamins and soil extract. These are present to some extent in Gulf water, and Odum, Hynes and Slater (16), have shown that charcoal may effectively remove them by adsorption. Since the organic portion of the substrate is very small, only small quantities of charcoal are needed. This work is in its preliminary stages, and there is no field work at present to show the effectiveness of carbon. Experiments are underway to show how effectively it strips out the growth-promoting matter, how many other organisms are affected, how long its effects last, and to what extent it penetrates (how deep it is effective). [p. 18.]

"Carbon has three other characteristics which recommend it. It is relatively cheap, and the supply is inexhaustible and readily available. It is not in itself toxic; it will not harm fish. There is no reason why it should affect organisms which have no organic requirements. Finally it has been shown by Block (17) that it will adsorb the waterborne toxin of brevis. The effect of this would be to cleanse water already poisoned. Clearly charcoal and activated carbon need a very careful investigation. [p. 18.]

"Biophysics has demonstrated many ways, principally through wave action, of affecting living microorganisms. Here again the work at the University of Florida is just beginning. It has already been shown, however, that there is no useful killing action in a high-frequency radio field. Cultures of five organisms, including brevis, were unaffected in glass containers in such a field. . . . [p. 18.]

The authors mentioned phosphorus as a possible cause of red tide and gave the following table of phosphorus values.

		ppm
2-19-53	Peace River, Arcadia, Odum	0.850
2-19-53	Peace River, Punta Gorda, Odum	0.240
3-30-53	Placida (Peace Estuary), Odum	0.028
4- 1-53	El Jobean (Peace Estuary), Odum	0.144
4-17-53	Bokeella (Peace Estuary), Odum	0.024
3- 7-54	Peace River, Punta Gorda, Odum and Hynes	0.670
3-18-54	St. James Point (Peace Estuary), Odum and Hynes	0.040
4- 3-53	Kissimmee River above L. Okeechobee, Odum	0.018
2-19-53	Lake Okeechobee, Moore Haven, Odum	0.039
2-19-53	Caloosahatchee Estuary, Sanibel, Odum	0.009
2-19-53	Caloosahatchee Estuary, Punta Rassa, Odum	0.060
3-30-53	Caloosahatchee Estuary, Ft. Myers Beach, Odum	0.042
3- 6-54	Caloosahatchee Estuary, Ft. Myers, Odum and Hynes	0.094
3- 6-54	60 miles off Naples, Odum	0.001
3- 6-54	70 miles off Naples, Odum	0.042
3- 6-54	80 miles off Naples, Odum	0.001

		ppm
3- 6-54	110 miles off Naples, Odum	0.001
4- 1-53	Hillsborough Bay, Odum	0.410
4- 7-53	Piney Point, Tampa Bay, Odum	0.120
4- 7-53	Pinellas Point, Tampa Bay, Odum	0.108
4- 6-53	Ballast Point, Tampa Bay, Odum	0.580
4- 6-53	Gandy Bridge, W. end Tampa Bay, Odum	0.240
3- 7-54	Tampa Bay, Odum and Hynes	0.410

Their reference in the table to Odum is apparently to a personal communication from Howard T. Odum, and their reference to Odum and Hynes is apparently Odum, Hynes, and Slater which they listed as a report in preparation entitled "Suggestion concerning the use of charcoal for control of 'red tide' blooms.

. . . . .

"All of the samples in the list above, except the last, indicate a progressive diminution of phosphorus as the water travels into the Gulf. . . ." [p. 19.]

The authors pointed out that to obtain the phosphorus values given by Ketchum and Keen for a 3-foot surface layer in a depth of 30 feet, all of the phosphorus would be concentrated by the organism in this surface layer. If the whole column was this rich in phosphorus, 17,000 pounds of pure phosphorus per square mile would be required. They then summarized by stating, "Actually brevis has been found blooming in water practically lacking in detectable phosphorus (June 18, 1954, Center of Lemon Bay, Tables IV and VII: phosphorus 0.000 ppm, brevis 4,814,000 per liter) and in water containing abundant phosphorus. . . ." [p. 20.]

The authors discussed nitrogen as a possible factor in blooms. They stated that Odum (personal communication) failed to find any nitrate nitrogen in a series of about 15 field samples in brevis water, Oct. 6, 1953. They quote him as stating "the suggestion is thus made that Gymnodinium [brevis] is not a nitrate user." [p. 20.]

. . . . .

"Except for changes in Gulf water due to dilution with land run-off, there seems little else which is peculiar to the brevis area. Ground water in the general area is frequently highly charged with H_2S. . . However, the ground-water springs in the Gulf flow constantly, and there are perhaps as many on the Atlantic side, where brevis has not been found. There is no reason to suspect that the flow is excessive during intermittent brevis outbreaks. John H. Davis [personal communication] says exposure of mangrove peat by storms might be a factor. This peat contains H_2S when first exposed, and has been accumulating for at least 5,000 years. Davis says it is four feet thick at Naples, but presumably it is equally thick on the Atlantic coast of Florida. [p. 21.]

"Organic acids (humic, tannic) are abundant in runoff from the West Coast, and [viewed] from the air, the brown discoloration as this water comes out of the passes is spectacular. . . ." [p. 21.]

Collier (1953b) "showed that titanium and zirconium were significantly present in the brevis area, but of themselves they have failed to be a stimulant in laboratory cultures. . . ." [p. 21.]

The authors disagreed with the conclusion of Chew (1953) that phosphorus is lower in river water than Gulf water.

The authors discussed the suggestion of Graham (1954) concerning the possible role of Skujaella (Trichodesmium) in causing blooms by concentrating phosphorus, but concluded that, "Neither the literature nor observations of this laboratory over the past few years have borne out the idea of an extensive algal bloom of blue-greens preceding Red Tide outbreaks." [p. 22.]

Meteorological and current effects "certainly come into play in distributing the land-contributed nutrients and in dispersing the organisms, and meteorological effects are seen when heavy weather breaks up a heavy brevis concentration. [p. 22.]

". . . Odum has measured the light intensity in varying concentrations of brevis, and while at the surface intensities may be very high, the organisms have been found concentrated at depths where the light intensity was greatly reduced. These and other considerations would seem to rule out light as a single decisive factor." [p. 22.]

LACKEY, JAMES B., and C. N. SAWYER.
1945. Madison lakes survey. II. Biological aspects. In Investigations of the odor nuisance occurring in the Madison lakes particularly Monona, Waubesa, Kegonsa from July 1943 to July 1944, p. 67-72. Rep. Gov.'s Comm., Wis. [Cited from Lackey and Hynes, 1955. Non vidi.]

LaCOSSITT, HENRY.
1954. The truth about Florida's Red Tide. Sat. Eve. Post 227(7):28ff. [Cited from Lackey and Hynes, 1955.]

Lackey and Hynes (1955) said concerning this article, "This point of human illness [enteric troubles from

eating shellfish from a red tide infected area] is emphasized by La Cossitt (5) in a popular journal."

LANGMUIR, IRVING.
1938. Surface motion of water induced by wind. Science 87(2250):119-123. [Cited by Ryther, 1955, and Pomeroy et al., 1956.]

Discusses the accumulation of floating objects in streaks parallel with the prevailing wind by wind-driven convection cells.

LASKER, REUBEN, and F. G. WALTON SMITH.
1954. Red tide. In Paul S. Galtsoff (coordinator), Gulf of Mexico: its origin, waters, and marine life, p. 173-176. Fish Wildl. Serv., Fish. Bull. 55.

This paper reviews red-tide outbreaks and factors which might cause overblooming of Gymnodinium brevis. The authors discounted the theory that blooming G. brevis is caused by upwelling of nutrient-rich water along Florida's west coast.

One possible cause given was increased phosphorus concentration, either by accumulation by G. brevis itself or by convergence of phosphorus-rich water masses.

It is also theorized that "The concentration of nutrients may have been the result of the lateral or vertical migration of some organism or organisms other than Gymnodinium. . . ." [p. 175.]

In a personal communication, George L. Clarke, of Harvard University theorized that "vertical migration linked with a subsequent horizontal concentration due to convergences of water masses may be the complete solution."

In 1950, phosphate deposits covering a 25-mile area were discovered off Tampa, Fla. ". . . The coincidence of these deposits with the area in which red tide outbreaks have occurred suggests that this may be a partial explanation of phosphorus availability.

"The problem presented is to account for periodic releases of nutrient salts from these bottom deposits. Possible explanations include shifts due to cataclysmic upsets in the ocean bottom or simple mechanical shifting of bottom muds due to strong bottom currents. . . ." [p. 175.]

River drainage was suggested as a source of mineral deposits; however, ". . . The remoteness of places like Key West and Cape Sable from river drainage areas where rich phosphate deposits are known to exist renders this explanation doubtful. . . ." [p. 175-176.]

LEBOUR, MARIE V.
1925. The dinoflagellates of northern seas. Mar. Biol. Lab., Plymouth, England, 172 p.

LEES, G. M.
1937. "Black Sea" conditions in the Arabian Sea. Amer. Ass. Petrol. Geol., Bull. 21(12):1579-1582.

LEWIS, GEORGE J., JR., and NORRIS W. RAKESTRAW.
1955. Carbohydrate in sea water. J. Mar. Res. 14(3):253-258.

Gives anthrone method of determining carbohydrates.

LONG, E. JOHN.
1953. The red tide hits and runs. Nature Mag. 46(3):125-128. [Cited from Biol. Abstr.]

The occurrence of the "red tide" dinoflagellate, Gymnodinium brevis, is discussed. Water samples taken during red tide have excess of N and P. Some relation is thought to exist between the heavy discharges of fresh water from the rivers of southwest Florida and the occurrence of the red tide.

LUCAS, C. E.
1947. The ecological effects of external metabolites. Biol. Rev. 22(3):270-295. [Cited from Ryther, 1955.]

LUCAS, C. E.
1949. External metabolites and ecological adaptation. Symp. Soc. Exp. Biol. III. Selective toxicity and antibiotics, p. 336-356. Academic Press, Inc., New York. [Cited from Ryther, 1955.]

LUND, E. J.
1935. Some facts relating to the occurrences of dead and dying fish on the Texas coast during June, July, and August 1935. Tex. Game Fish Oyster Comm., Annu. Rep. for the fiscal year 1934-35:47-50.

Gives observations on dead fish washed ashore in the vicinity of Port Aransas from June 30 to August 13. Most of the fish were in an advanced state of decay when they washed ashore.

"The escape of irritating 'gas' dissolved in the sea water was facilitated by prevailing winds blowing on shore. Appearance of 'gas' was always associated with the simultaneous or immediately previous appearance of dead fish. . . . [p. 48.]

. . . . . .

". . . an examination of the Weather Bureau reports on Texas for 1934-5 shows that rainfall and flood levels of the rivers were at unusual maxima during May and June, 1935. A maximum of the resulting outflow of water of very low salinity through the passes occurred during the last week in June and therefore just preceding the first appearance of dead fish on Padre Island. . . ." [p. 49.]

MARGALEF, RAMON.
1963. Succession in marine populations. In Raghu Vira (editor), Advancing frontiers of plant sciences, vol. 2, p. 137-188. Institute for the Advancement of Sciences and Culture, New Delhi 16, India.

MARTIN, G. W., and THURLOW C. NELSON.
1929. Swarming of dinoflagellates in Delaware Bay, New Jersey. Bot. Gaz. 88(2): 218-224.

They described discolored water occurring in late summer of 1928 in Delaware Bay, N.J. It extended from the shore to about 7 m. out, where the depth was 2 m. The chief organism was *Amphidinium fusiforme*. Oysters exposed during low tide were examined after being covered half a meter and were found to be full of the organisms.

Some patches of "red" water contained *Gymnodinium*. They found when they were killed with a strong solution of iodine in potassium iodide and examined microscopically that each cell was surrounded by a gelatinous envelope as thick as the diameter of the cell itself, so that the water in which they occurred must have been a nearly continuous mass of soft jelly. The envelope is also visible, but less apparent, if the organisms are killed in a saturated solution of bichloride of mercury. The envelope is less regularly seen in material killed in osmic acid and then transferred to chrom-acetic solution, and never in any of the other reagents used.

". . .Gelatinous envelopes are common among dinoflagellates when encysted, but not when active. The cells referred to in this connection were actively motile. A similar envelope has been noted occasionally surrounding other species of naked dinoflagellates in the active condition, but only when killed by the iodine or bichloride methods. In red water plankton in which *Amphidinium fusiforme* is the dominant species, the *Amphidinium* cells tend to cling together in clumps, but no gelatinous envelope can be demonstrated. In many of the clumps (although not in all), however, they may be seen to be clustered thickly about a cell of the *Gymnodinium*. This gelatinous envelope may well be a factor of importance in holding the organisms together, once they are massed by a favorable combination of light, water temperature, and tidal currents." [p. 223.]

MARVIN, KENNETH T.
1955. Oceanographic observations in west coast Florida waters, 1949-52. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 149, i + 32 p.

This report presents raw hydrographic data collected by the Fish and Wildlife Service from May 1949 through July 1951. Data do not extend into 1952 as the title of the paper implies. Data were collected by the vessel *Pompano* from 10 stations (1 in Charlotte Harbor and 9 offshore to as far as 120 miles). Two other stations were in the Peace and Caloosahatchee Rivers. Station data include temperature, salinity, oxygen, inorganic and total phosphorus, pH, and nitrites.

MARVIN, KENNETH T.
1958. Copper ore experiments for red tide control. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 78-85.

Most of this material is discussed in Marvin et al. (1961).

". . .the source of copper would have to be capable of releasing a relatively small amount of copper into solution over a long period of time. . . .The particular ore under consideration is a sulphide ore containing roughly 1 percent copper, 3.5 percent iron and 6 percent sulphur.

"Preliminary investigations have shown that the ore in a closed system (4 pounds of ore in 120 gallons of sea water) will liberate a maximum of about 1.5 parts per million of copper in about a day's time. This then tapers off to about 0.9 part per million; the excess copper is presumably precipitated as the rather insoluble compound, basic copper carbonate. . . ." [p. 78-79.]

MARVIN, KENNETH T.
1959. Testing copper ore for red tide control. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 86-94. U.S. Fish Wildl. Serv., Circ. 62.

"Field tests have been conducted to determine the effects of copper sulphate on *G. breve* when applied as crystals

and also as a concentrated solution. These tests were conducted during red tide outbreaks on the west coast of Florida in 1952, 1953, 1954, and 1957. Copper sulphate dissolves rapidly in sea water supersaturating the ambient water with copper. The resulting concentration is many times that of the required lethal level as determined in laboratory toxicity experiments, but this high concentration does not last long. The bulk of the copper precipitates as the basic carbonate and is dispersed by tides and currents and the copper concentration is reduced to an ineffective level." [p. 87.]

The report gives details of the leaching rate of copper ore and of the copper ore experiments. For the results see Marvin et al. (1961).

MARVIN, KENNETH T.

1960. Chemical control experiments. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 43-45. U.S. Fish Wildl. Serv., Circ. 92.

The need is pointed out for a chemical toxic to G. breve at low concentrations, selective as to the organism it affects, and without the precipitating characteristics of copper.

Results of 16 replicate experiments at six concentrations of $CuSO_4 \cdot 5H_2O$ indicated that the critical concentration of copper for 100-percent mortality of G. breve lies between 0.39 and 0.80 ug.at./l.

The screening of 4,000 compounds revealed the following numbers toxic to G. breve at five concentrations shown below:

Compounds containing--	Total number tested	Total toxic at: 0.01 p.p.m.	0.04 p.p.m.	0.10 p.p.m.	0.40 p.p.m.	1.0 p.p.m.
Amines........	856	19	83	117	242	328
Nitro.........	496	1	8	27	79	117
Phenol........	236	8	29	49	95	127
Mercury.......	28	6	10	12	13	13
Sulfur........	592	9	31	61	169	235
Amides........	228	3	4	11	35	42
Cyanides......	202	1	13	19	59	93
Copper........	32	0	1	2	16	27
Quinones......	13	0	5	7	7	10
Total.......	[1] 2,683					

[1] Excludes compounds too insoluble to test.

The author points out that there are several errors in this type of large-scale testing.

MARVIN, KENNETH T., LARENCE M. LANSFORD, and RAY S. WHEELER.

1961. Effects of copper ore on the ecology of a lagoon. U.S. Fish Wildl. Serv., Fish. Bull. 61:153-160.

Laboratory experiments had shown copper as lethal to Gymnodinium breve at a minimum concentration of about 0.5 ug.at./l. (0.03 p.p.m.). The experiment was to discover whether immersed copper ore could raise the dissolved copper content of the water sufficiently to destroy G. breve and, if so, whether other organisms would be seriously affected.

After a 9-month study of the flora and fauna of a small (230-acre feet) salt-water lagoon, 60 tons of copper ore were added. The average copper levels in the lagoon did not attain toxic levels. It was concluded that use of copper ore is not a feasible control method.

MARVIN, KENNETH T., and RAPHAEL R. PROCTOR, JR.

1961. Chemical control. In Galveston Biological Laboratory fishery research for the year ending June 30, 1961, p. 59-60. U.S. Fish Wildl. Serv., Circ. 129.

See Marvin and Proctor (1964).

MARVIN, KENNETH T., and RAPHAEL R. PROCTOR, JR.

1964. Preliminary results of the systematic screening of 4,306 compounds as "red-tide" toxicants. U.S. Fish Wildl. Serv., Data Rep. 2, 3 microfiches (i+85 p.).

Each compound was tested at five concentrations ranging from 0.01 to 1.0 p.p.m. Because of variation in solubility some differences occurred between the actual concentration tested and that shown. The chemicals were tested for their efficiency in killing Gymnodinium breve over a 24-hour test period. A culture of G. breve stock containing from 1 to 2 million organisms per liter was used.

The objective was to discover compounds 100 percent lethal to G. breve at the 0.04 p.p.m. level. The total results were:

Concentration in p.p.m.	Number toxic
0.01	55
.04	191
.10	284
.40	740
1.00	1,047

Not toxic at 1.00--- 3,259

The compounds toxic at 0.04 p.p.m. are being tested against other marine organisms to determine their specificity for the red-tide organism.

MATODA, S.

1944. Sea and plankton. Kawade Shobo Publ., 235 p. [Cited from Fish and Cobb, 1954.]

According to Fish and Cobb, Matoda said observations by K. Nakazawa indicated that early larvae of mollusks and crustaceans, which breathe through the body surface, survive in discolored water, while older forms with specialized respiratory gills are killed when these organs become completely covered with the disintegrating bodies of dinoflagellates. These and similar observations by K. Oda on oysters in Gokasho Bay when *Gymnodinium mikimoti* Miyaki and Kominani swarmed in 1934, led to the conclusion that the detrimental effect is of a physical rather than chemical nature.

MAY, BILLIE Z.

1964. A collection of data in reference to red tide outbreaks during 1963. 6. Environmental chemistry: January through May, 1963. Fla. Bd. Conserv., Mar. Lab., p. 108-121.

For 18 stations in Tampa Bay and adjacent waters in January through May, 1963, author gives salinity, oxygen, calcium, total phosphate, surface chlorophyll A, and ultra-violet absorption values (given as optical density on a Beckman DU spectrophotometer with a 1 cm. cell; measured 220 mμ). Samples were filtered before measurements with a millipore HA filter of 0.8 pore size.

The author ascribed the variations in the optical-density readings to the presence of dissolved organics, citing Armstrong and Boalch (1961). The optical-density readings are fairly well correlated with salinity. For nine of the K stations taken each month from February through May a correlation of -0.75 indicates much higher absorption of light as the sea water becomes diluted with river water. Plotting of the optical-density readings against chlorophyll A for the same stations shows also an increase in optical density as chlorophyll A increases.

McFARREN, EARL F.

1963. Human illness produced by eating Sarasota and Charlotte County, Florida, oysters, I. Analysis of samples. Robert A. Taft Sanitary Eng. Center, Public Health Service, p. 1-4.

Assays on mice suggested that the poison from the oysters resembled "ciguatera" fish poison rather than the usual paralytic shellfish type. Samples from all five Gulf States in December 1962, were negative except for oysters of Sarasota and Charlotte Counties.

McFARREN, E. F., M. L. SCHAFER, J. E. CAMPBELL, K. H. LEWIS, E. T. JENSEN, and E. J. SCHANTZ.

1957. Public health significance of paralytic shellfish poison: a review of literature and unpublished research. Proc. Nat. Shellfish. Ass. 47:114-141.

The significant feature of this paper is failure to mention either *G. breve* or oysters in connection with shellfish poisoning. See McFarren et al. (1960).

McFARREN, EARL F., MARY L. SCHAFER, JEPTHA E. CAMPBELL, KEITH H. LEWIS, EUGENE T. JENSEN, and EDWARD J. SCHANTZ.

1960. Public health significance of paralytic shellfish poison. Advances Food Res. 10:135-179.

In this report it is stated that the only known case of shellfish poisoning from eating oysters occurred in Baynes Sound (western side of the Gulf of Georgia), British Columbia, from eating cultivated Japanese oysters, *Crassostrea gigas*.

". . .The appearance of the poison in the oysters was accompanied by a much higher level of toxicity in butter clams in adjacent areas, while little neck clams, razor clams, and cockles exhibited a relatively lower level of toxicity. In this instance, the oysters appeared to rid themselves of the poison more rapidly than other bivalves after the ingestion of the toxic plankton had ceased." [p. 145.]

McKEE, JACK EDWARD, and HAROLD W. WOLF (EDITORS).

1963. Water quality criteria. 2d ed. The Resources Agency Calif. State Water Quality Control Board, Publ. 3-A, 548 p.

The section on marine flagellates (p. 323-324) gives various summary statements and sources from which they were derived. The statements, however, have not been updated; so theories put forth a number of years ago which seemed reasonable in the light of existing knowledge, but which have been superseded by later work, are given as facts. For instance, it is stated that sulfides are essential for mass development of the red-tide organism, giving

as authority an anonymous "fill in" note on the bottom of a page of the Progressive Fish-Culturist for July 1953.

McLAUGHLIN, JOHN J. A.

1956. The physiology and nutritional requirements of some chrysomonads. Ph. D. Thesis, New York Univ., 65 p. [Reference from Ray and Wilson, 1957, p. 493. Non vidi.]

Ray and Wilson (1957) stated, "McLaughlin working with the same organism [*Prymnesium parvum*] reported that cultures grown in an alkaline medium were more toxic than those grown in an acid medium. *P. parvum* cultures (grown in alkaline media), rendered nontoxic by lowering the pH to 6.0, regain their toxicity when made alkaline (Shilo and Aschner, 1953; McLaughlin)."

McLAUGHLIN, J. J. A.

1958. Euryhaline chrysomonads: Nutrition and toxigenesis in *Prymnesium parvum*, with notes on *Isochrysis galbana* and *Monochrysis lutheri*. J. Protozool. 5(1): 75-81.

"The nutritional requirements of 3 isolates of *Prymnesium parvum* (2 Israeli, 1 Scottish) included vitamin B_{12} and thiamine. For comparison, 2 other brackish chrysomonads were studied: *Monochrysis lutheri* isolated by Droop in Scotland and *Isochrysis galbana* purified by McLaughlin from a culture obtained from the Plymouth laboratory.

"The isolates of *Prymnesium parvum* and *Isochrysis galbana* had a molecular B_{12} specificity like *Ochromonas malhamensis*: no response to Factor B, pseudovitamin B_{12}, Factor A or Factor H. *M. lutheri*, in contrast, responded to pseudovitamin B_{12}, Factor H, and Factor A.

"Thiamine was essential; 1.0 ug. % allowed full growth of *P. parvum*. The NaCl concentration for good growth was 0.3-5.0%; growth was possible from 6-12%. Dark growth was not achieved.

"Ammonia, as suggested from its use in suppressing outbreaks of *P. parvum*, was sharply inhibitory, less so at high concentrations of NaCl or at acid pH.

"Nitrate, ammonia, arginine, asparagine, methionine, histidine, alanine, glycine, serine, proline, leucine, isoleucine, tyrosine, aspartic and glutamic acids, acetylurea, and creatine served as nitrogen sources in both acid and alkaline media.

"The phosphate requirement of *P. parvum* and *M. lutheri* and *Isochrysis galbana* was satisfied by inorganic phosphate, commercial glycerophosphate, yeast adenylic acid, cytidylic acid, monoethyl phosphate, and riboflavin monophosphate.

"Laboratory cultures in defined media of the isolates of *P. parvum* were toxigenic to *Lebistes* and *Gambusia*. Culture fluids from alkaline media were more toxic than those from acid media, as previously noted in Israel.

"Culture media suitable for production of large quantities of these organisms were developed." [p. 75.]

McLAUGHLIN, JOHN J. A., and LUIGI PROVASOLI.

1957. Nutrition requirements and toxicity of two marine *Amphidinium*. J. Protozool. 4 (suppl.):7.

Amphidinium klebsii (?) and *A. rhyncocephalum* require vitamins B_{12}, thiamine, and biotin.

MEAD, A. D.

1898. *Peridinium* and the 'red water' in Narragansett Bay. Science, n. s. 8(203): 707-709; also in Rep. U.S. Comm. Fish Fish. 1899, p. CXLII.

MENON, M. A. S.

1945. Observations on the seasonal distribution of the plankton of the Trivandrum coast. Proc. Indian Acad. Sci. B22:31-62. [Cited by Ryther, 1955.]

Blooms of *Gymnodinium* sp. occur annually during June to September along the Trivandrum Coast of India, following rains and diatom maxima.

MITSUKURI, K.

1905. The cultivation of marine and fresh-water animals in Japan. U.S. Bur. Fish., Bull. 24:259-289.

"As in all culture enterprises, there are many enemies of the pearl oyster, as well as unexpected difficulties in the way of its culture. *Octopus*, *Codium*, *Clione* (sponges), all sometimes play a sad havoc among the mollusks, but the most dreaded enemy of all is the 'red current' or 'red tide.' This is an immense accumulation of a Dinoflagellata, *Gonyaulax*, causing discoloration of the sea water, and, in some way not well accounted for, causing in its wake an immense destruction of marine organisms, large and small." [p. 284.]

MIYAJIMA, M.

1934. La question de "l'eau rouge" un péril pour les huitres perlières. Bull. Soc. Gén. Agr. Pêche 41:97-110. [Non vidi.]

MOE, MARTIN A.
1964. A collection of data in reference to red-tide outbreaks during 1963. 7. A note on a red tide fish kill in Tampa Bay, Florida, during April 1963. Fla. Bd. Conserv., Mar. Lab., p. 122-125.

Identified 52 species of fish killed in the outbreak.

MONTAGNE, C.
1844. Sur le phénomène de la coloration des eaux de la mer rouge. Ann. Sci. Nat., ser. 3, Bot. 2:332-362. [Non vidi.]

MOORE, M. A.
1882. Fish mortality in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4:125-126.

"About two years ago [1878] certain portions of our Gulf waters became poisoned in some way that caused the death of all the fish that came in contact with it. Whenever a smack with a full fare, i.e., a full cargo of fine healthy fish in her well, sailed into this poisoned water every fish would die, and they would have to be thrown away.

"This state of affairs has occurred again [1880]; the waters of some portions of the Gulf becoming so noxious as to kill the fish. The poison seems to be confined to certain localities and currents for the time being, as sometimes this state of affairs is observed more marked at one place and sometimes at another. However, there seems to be more of it about the mouth of Charlotte Harbor and off Punta Rassa than elsewhere." [p. 125.]

MUNK, WALTER H., and GORDON A. RILEY.
1952. Absorption of nutrients by aquatic plants. J. Mar. Res. 11(2):215-240. [Cited by Ryther, 1955.]

NELSON, THURLOW C.
1948. Red oysters. N.J. Fisherman (Nov.) [Cited from Pomeroy et al., 1956. Non vidi.]

Red oysters, exuding blood-red liquor, were associated with dinoflagellate blooms in Delaware Bay.

NIGHTINGALE, H. W.
1936. Red water organisms. Their occurrence and influence upon marine aquatic animals, with special reference to shellfish in waters of the Pacific Coast. The Argus Press, Seattle, Wash. 24 p. [Non vidi.]

Reviewed red-water worldwide occurrences since 1871.

NISHIKAWA, T.
1901. Gonyaulax (Polygamma) and the discolored water in the Bay of Agu. Annot. Zool. Jap., Part I, IV: 31-34.

An outbreak of red water by Gonyaulax polygamma did no damage; earlier outbreaks in some localities were reported to be highly destructive to pearl oysters, fishes, and crustaceans.

NORDLI, E.
1953. Salinity and temperature as controlling factors for distribution and mass occurrence of Ceratia. Blyttia 11:16-18. [Cited from Ryther, 1955.]

NÜMANN, WILHELM.
1957. Natürliche und künstliche "red water" mit anschliessenden Fischsterben im Meer. (Natural and artificial "redwater" with associated fish mortalities in the sea). Arch. Fischereiwiss. 8(3):204-209. [Summarized from a translation by Alexander Dragovich.]

He personally observed in the Bodensee how whitefish avoided the areas having heavy diatom concentrations.

Author observed an outbreak off the coast of Angola during August 1951. He stated that the nutrient-rich zone extends from Angola to Lobito-Benguela, where the Benguela current deflects to the west. At the end of July and the beginning of August he observed an explosionlike outburst of phytoplankton a little north of the mouth of the Congo. As he traveled south, yellowish-brown and red masses of plankton occurred for 600 km. to Lobito, north of the nutrient-rich coastal waters. The plankton masses were never observed on the surface farther than 10 miles offshore. A deep red was seldom observed; instead, a brownish-yellow was much more frequently noted.

During the first half of September 1951, water in the Bay of Luanda was blood-red, and enormous quantities of dead fish covered the surface. He took plankton samples 5 miles off the coast of Luanda on July 27, at the beginning of the outbreak. In individual samples (analyzed by De Sousa e Silva, 1953) 69 to 92 percent was Exuviella baltica Lohmann. Prorocentrum micans Ehrenberg and Prorocentrum sp. constituted up to 10 percent, and Peridinium sp. up to 13 percent.

He described an outbreak of red tide in the Bay of Izmir (Agean Sea) caused by a species of Gymnodinium. The water was coffee brown to yellowish

or greenish. He speculates on the cause of the fish mortality, ascribing it partially to suffocation and partially to toxic substances.

A translation of his remarks on both outbreaks follows: "The outburst of red water never occurs in the open sea, but always in bays and coastal waters which are rich in nutrients. According to all reports, outbreaks of red water most obviously occur in coastal areas a short time after precipitation. The bloom of Exuviella occurred in the coastal area of Angola after heavy rainfall in the hills of Binnenland. The Congo and Cuanza Rivers brought much water which was spread throughout the surface layers of coastal waters.

"It also appears--and this is our final conclusion--that a mass outburst of phytoplankton occurs when fresh-water growth-promoting substances (trace elements, enzymes, or other biologically active substances) reach the sea. Due to the presence of a necessary quantity of nutrients in the sea, a pre-condition for the outburst of plankton in the sea exists already. Accordingly, these outbursts occur only near the coast."

ODUM, HOWARD T.
1953. Dissolved phosphorus in Florida waters. Fla. State Bd. Conserv., and Fla. Geol. Surv., Rep. Invest. 9(1):1-40.

"The extensive deposits of phosphate rock in Florida lead to unusually high dissolved phosphorus contents in the streams and lakes which drain these areas. . . . Additional quantities of dissolved phosphorus are being added by sewage and industry in some areas, although little recognition has been made of the possibly large biological effects that relatively small amounts of added phosphorus can have on those areas which are not receiving drainage from phosphate areas. The moderately low phosphorus content of basic springs in contrast to acid surface streams suggests a controlling role of pH in phosphorus solubility in Florida." [p. 1.]

This report contains several maps showing the phosphate-bearing formations and the concentrations of dissolved phosphorus in Florida waters. Separate figures are shown for the Peace River, the Tampa Bay, the South Florida, and the St. Johns River areas.

He stressed the effect of sewage in greatly increasing the phosphorus content of lakes and streams. Thus, he gave the phosphorus for 18 small unpolluted streams as 0.019 p.p.m.; for 10 small acid streams draining phosphatic formations as 0.413 p.p.m.; and 7 streams not draining phosphatic formations but receiving sewage the phosphorus as 0.836 p.p.m.

ODUM, HOWARD T., J. B. LACKEY, JACQUELINE HYNES, and NELSON MARSHALL.
1955. Some red tide characteristics during 1952-1954. Bull. Mar. Sci. Gulf Carib. 5(4):247-258.

A report on miscellaneous red-tide data (total nitrogen, phosphorus, and counts of G. breve--45 determinations with both N and P) from coastal waters. Summary table does not give range of values in the five localities sampled. Other data are mentioned (chlorophyll, light measurements, and B.O.D.) but not presented, although some results are discussed. G. breve counts were made from samples preserved in 5 percent formalin and centrifuged. The data are rather meager for reliability. Odum said Olson (1953) showed that the fresh water entering Tampa Bay takes 2 to 3 years to accumulate a volume equal to that of the bay and, thus, to complete a turnover.

The increasing multiple pollution of the shallow coastal estuaries is given as possibly the cause of a higher incidence of red tide than might otherwise occur.

A footnote mentions that Odum and Hynes, at the 1954 meeting of the American Society of Limnology and Oceanography in Gainesville, Fla., suggested the large-scale dusting of charcoal as a possible means of absorbing required vitamins and, thus, modifying the nature of offshore blooms.

OLSON, F. C. W.
1953. Tampa Bay studies. Fla. State Univ., Oceanogr. Inst., Rep. 1:1-27.

Fresh waters entering Tampa Bay take 2 to 3 years to accumulate a volume equal to that of the Bay.

OTTERSTRØM, C. V., and E. STEEMANN NIELSEN.
1939. Two cases of extensive mortality in fishes caused by the flagellate, Prymnesium parvum, Carter. Rep. Danish Biol. Sta. 44:5-24.

"The effect of the poisoning is of a permanent nature, the conveyance of an apparently unhurt fish to pure water does not by far in all cases save the fish." The flagellate itself is not poisonous; the damages must be caused

by some matter contained in the water and most likely originating from the metabolism of the flagellate.

PAULSEN, OVE.
1934. Red "water bloom" in Iceland seas. Nature 134(3399):974.

PEARSALL, W. H.
1932. Phytoplankton in the English lakes. II. The composition of the phytoplankton in relation to dissolved substances. J. Ecol. 20(2):241-262. [Cited from Ryther, 1955.]

PETERS, N.
1929. Über Orts- und Geisselbewegund bei marinen Dinoflagellaten. Arch. Protistenk. 67(2/3):291-321.

Pomeroy et al. (1956) cited Peters (1929) and Hasle (1950, 1954) as suggesting that some species of dinoflagellates can oppose successfully a vertical current of about 1 cm./sec.

PHELPS, EARLE B., and DAVID E. BARRY.
1950. Stream sanitation in Florida. Univ. Fla., Eng. Ind. Exp. Sta., Bull. 34:1-56.

Gives amounts of sewage from St. Petersburg and Tampa.

PIERCE, H. D.
1883. 53--The spawning of bluefish--an opinion of the cause of mortality of fish in the Gulf of Mexico. U.S. Fish Comm., Bull. 3:332.

This reference, cited by others, has no bearing on red tide.

PINTNER, I. J., and L. PROVASOLI.
1963. Nutritional characteristics of some chrysomonads. In Carl H. Oppenheimer (editor), Symposium on marine microbiology, ch. 11, p. 114-121. Charles C. Thomas, Springfield, Ill.

POMEROY, LAWRENCE R., HAROLD H. HASKIN, and ROBERT A. RAGOTZKIE.
1956. Observations on dinoflagellate blooms. Limnol. Oceanogr. 1(1):54-60.

Discusses dinoflagellate blooms in Delaware Bay and in tidal creeks on Sapelo Island, Ga. The Delaware Bay blooms were caused by a mixture of Amphidinium fusiforme and Gymnodinium splendens. ". . .All the Delaware Bay blooms occurred during periods of light winds, not exceeding Beaufort force 2. On one occasion a patch disappeared when the wind rose from force 2 to 3. The blooms were all limited to the surface layer of the water, even in the absence of a significant density gradient. In addition to being concentrated at the surface, the blooms were typically in the form of elongated slicks with abrupt margins. This was also true in the 1952 bloom. . . .

"No mortality of marine organisms was associated with the blooms. However, a few days after the appearance of the 1952 bloom local oyster packing companies began to complain of 'red oysters'. The red material was concentrated in the digestive glands of the oysters. After several days in cold storage the liquor of the shucked oysters became blood-red. Several weeks later, oysters in nearly all parts of Delaware Bay had developed dark red digestive glands. They no longer exuded red liquor after being shucked, and the wet volume of meats per bushel of oysters increased from 4 or 5 pints per bushel to 8. . . . ." [p. 56.]

The authors described several blooms of Gymnodinium sp. in the headwaters of Duplin River, a wholly tidal stream, with no vertical or horizontal salinity gradient. At the time of one bloom (April 21, 1955) it was noted that the bloom disappeared at night and in the early morning on 4 successive days, reappearing each day at about 0900. As the bloom was concentrated in several patches near the downwind shore, they released widely spaced current drags 10 cm. in depth, ballasted to float in the upper 10 cm. of water. These drags demonstrated convergence of surface water by all drifting and remaining close together in the center of a dense concentration of dinoflagellates.

The organisms were phototactic; by moving the light source it was found they moved between 0.3 and 0.8 cm./sec.

"The observation that blooms occur only during light winds suggests that at wind velocities of Beaufort 3 or more the speed of the current vortices exceeds the swimming speed of the dinoflagellates. . . ." [p. 58.] They cite Peters (1929) and Hasle (1950,1954) as confirming the suggestion that some species of dinoflagellates can oppose successfully a vertical current of 1 cm./sec. They then say that "Langmuir's (1938) measurements suggests that this vertical velocity is exceeded in wind-induced vortices somewhere between Beaufort 2 and 3." They noticed subsurface depletion of phosphorus and high surface concentration during the 1953 Delaware Bay bloom,

which they state could be easily accounted for by current vortices extending down only 1 or 2 m.

". . . Before the influence of trace metals, vitamins, or other organic materials can be determined, improved field methods for their quantitative estimation are needed. This remains one of the most serious deficiencies in our knowledge of the causative factors of dinoflagellate blooms." [p. 59.]

PORTER, JOSEPH Y.
1882. On the destruction of fish by poisonous water in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4:121-123.

This report contains chiefly conjecture, attributing the fish kills to swamp water poisoned by dogwood, or to submarine springs. Fishermen catching fish north of Pine Island, Charlotte Harbor, were losing fish in their live wells on the way to Havana. Concerning the submarine spring it is stated, ". . .One proof of its volcanic orgin is that the water so polluted is of a 'red brick color,' at a distance of less than a mile from the shore. . . ." [p. 123.]

POWERS, EDWIN B.
1938. Factors involved in the sudden mortality of fishes. Trans. Amer. Fish. Soc. 67:271-281.

PRATJE, A.
1921. *Noctiluca miliaris* Suriray. Beiträge zur Morphologie, Physiologie, und Cytologie, I: Morphologie und Physiologie (Beobachtungen an der lebenden Zelle). Arch. Protistenk. 42: 1-98. [Non vidi.]

PROVASOLI, LUIGI.
1958. Nutrition and ecology of protozoa and algae. Annu. Rev. Microbiol. 12:279-308.

Gives summary table of vitamin requirements of numerous algae from many authors; 165 references.

PROVASOLI, L., and J. J. A. McLAUGHLIN.
1963. Limited heterotrophy of some photosynthetic dinoflagellates. *In* Carl H. Oppenheimer (editor), Symposium on marine microbiology, ch. 10, p. 105-113. Charles C. Thomas, Springfield, Ill.

RATHBUN, RICHARD.
1895. Mortality of oysters in Galveston Bay. *In* Report upon the inquiry respecting food-fishes and the fishing-grounds, p. 23-26. U.S. Comm.Fish Fish., Rep. Comm., pt. 19, for year ending June 30, 1893.

RAY, SAMMY M., and WILLIAM B. WILSON.
1957. Effects of unialgal and bacteria-free cultures of *Gymnodinium brevis* on fish, and notes on related studies with bacteria. U.S. Fish Wildl. Serv., Fish. Bull. 57:iii + p. 469-496; also U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 211, iv + 50 p.

Extensive experiments were performed to prove that *Gymnodinium breve* produces a toxin that kills fish. Experiments showed that cultures of *G. breve* killed fish, while cultures of *G. splendens* and of *Prorocentrum* sp. did not.

Experiments with *Flavobacterium piscicida* failed to show any toxic effect. Lasker (Bein, 1954) had isolated this red-pigmented bacterium; Bein's experiments indicated 24-hour cultures killed several species of marine fish. Experiments showed that water already made toxic does not lose its toxicity for some time after the removal of *G. breve*. Likewise, the occurrence of any condition unfavorable to the organism may cause disintegration of the cells so that the water may be toxic even though it contains only fragmentary remains of *G. breve* cells that are not readily identifiable.

Filtrates of *G. breve* passed through a millipore filter under suction proved more toxic than filtrates passed by gravity through filter paper. The authors suggested this difference may be due to more organisms being retained intact by the filter paper.

They found no indication that fish kills by *G. breve* result from depletion of oxygen by the great masses of the organism.

The degree of toxicity of *G. breve* cultures was influenced, aside from concentration, by such factors as the growth phase of the culture, the pH of the culture during the growth and the test periods, temperature and salinity of the test culture, the size and number of the test fish, the volume and degree of aeration of the test culture, and bacterial growth.

"Bacteria-free cultures of *G. brevis* with concentrations varying from 2.3 to 4.8 million organisms per liter were toxic to two species of test fish. Five species of fish were killed when subjected to unialgal *G. brevis* cultures containing 0.6 to 2.1 million organisms per liter. . . ." [FB., p. 495.]

RICE, THEODORE R.
1954. Biotic influences affecting population growth of planktonic algae. Fish Wildl. Serv., Fish. Bull. 54:ii + p. 227-245.

"It is concluded that antagonistic substances arising from the metabolism of phytoplankton are important, at least in fresh-water ponds, in influencing the seasonal fluctuations in total phytoplankton numbers and in the numbers of each species, as well as in causing a definite succession of species." [p. 244.]

ROBINSON, REX J., and THOMAS G. THOMPSON.
1948. The determination of phosphates in sea water. J. Mar. Res. 7(1):33-41.

The authors stated, "If the samples of sea water contain much plankton this should be removed by filtration or centrifugalization. However, it is only in extreme cases when such a procedure is necessary." [p. 38.] Not discussed are errors in phosphorus determinations from particulate phosphorus in unfiltered samples.

ROTBERG, M.
1958. The thiamine requirements of Prymnesium parvum (Chrysomonadina). Bull. Res. Counc. Israel 7B:208-210.

ROUNSEFELL, GEORGE A.
1958. Large-scale experimental control of red tide. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 76-77.

Information herein published by Rounsefell and Evans (1958).

ROUNSEFELL, GEORGE A., and JOHN E. EVANS.
1958. Large-scale experimental test of copper sulfate as a control for the Florida red tide. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 270, vi + 57 p.

Gives results of the first large-scale attempt to control overblooming of the red-tide organism, Gymnodinium breve. ". . . About 16 square miles stretching along 32 miles of shoreline from Anclote Key to Pass-a-Grille Beach, off St. Petersburg, Florida, were dusted with copper sulfate ($CuSO_4.5\ H_2O$) at about 20 pounds to the acre by crop-dusting planes. . . ." [p. iii.]

In March 1958, after the completion of the manuscript of this report, a selected panel of 14 biologists versed in this field of research were invited by the Director of the Bureau of Commercial Fisheries to a symposium on red tide held at Galveston, Tex. It was the concensus of this group, after mature consideration of the copper sulfate experiment, that the combination of excessive cost, short duration of control, and possibility of harm to other marine life renders application of the method inadvisable.

RYTHER, JOHN H.
1955. Ecology of autotrophic marine dinoflagellates with reference to red water conditions. In Frank H. Johnson (editor), The luminescence of biological systems, p. 387-414. Amer. Ass. Advance. Sci., Wash. D.C.

"The dense populations of dinoflagellates which create 'red water' conditions are known only in the tropics or in temperate water during the warmer (and usually the warmest) time of the year. . . .

"Such fragmentary physiological evidence as is available concerning the temperature relations of dinoflagellates appears to support the view that they are predominantly a warm-water group. Barker (1935), who is one of the pioneers in developing successful culture methods for dinoflagellates, observed optimal temperatures for the growth of some 14 species between 18° and 25° C. Braarud and Pappas (1951) noted a temperature optimum for Peridinium triquetrum at 18° C, while Nordli (1953) found that Ceratium fusus and C. furca grew most rapidly at temperatures of 15° and 20° C respectively. Provasoli (personal communication) finds temperatures of 20-25° C most suitable for growing Gyrodinium californicum. . . ." [p. 389-390.]

The author gave the following table to show preferred salinities:

Optimum and Maximum Range of Salinity for Growth of Some Neritic Dinoflagellates

Reference	Species	Optimum, ‰	Range, ‰
Nordli (1953)	Ceratium furca	25	10-40
	Ceratium tripos	20	10-35
	Ceratium fusus	20	10-40
Braarud (1951)	Amphidinium sp.	15	5-45
	Exuviella baltica	18	5-35
	Peridinium trochoideum	20	5-60
Braarud and Rossavik (1951)	Prorocentrum micans	15-20	10-45
Braarud and Pappas (1951)	Peridinium triquetrum	15-20	10-40

"While all the species have salinity optima well below that of full sea water, it is perhaps of even greater significance that they are also able to grow within

an extremely wide range of salinities. This high degree of adaptability is a definite advantage to life in the variable environment of coastal and estuarine waters, and it is perhaps one of the means by which the neritic dinoflagellates are able to compete successfully with other organisms, such as diatoms, which in general have a more narrow range of salinity tolerance." [p. 391.]

The author, citing Fritsch (1935), mentioned that the naked dinoflagellates appear to be most abundant in the open ocean plankton, while the armored forms are more typical of coastal and estuarine regions.

"The dinoflagellates have often been credited with the ability to utilize and flourish in extremely low concentrations of nitrogen and phosphorus (Gran, 1926-27; Gilson, 1937). This concept has stemmed largely from observations that dinoflagellate maxima, in temperate waters, follow the decline of the spring diatom flowerings and relatively large populations often persist throughout the summer months when the supplies of these nutrients are almost undetectable. Gran (1926-27) has proposed that the dinoflagellates require less nutrition for growth than the diatoms on account of their relatively low rate of metabolism. [p. 391-392.]

. . . . .

". . . dinoflagellates as a group show a continuous variation in their modes of nutrition from autotrophic to holozoic, while many species are facultative, obtaining their food by either or both methods (Kofoid and Swezy, 1921). . . . [p. 392.]

. . . . .

"In inshore waters dinoflagellates are often abundant, and in many parts of the world their populations may develop bloom proportions. Here the close association of the plankton with land masses and the contribution of runoff water to their environment provide what may be considered as a natural 'soil extract,' and, in the vicinity of heavily populated areas, frequently a source of organic pollutants. As mentioned earlier, Braarud (1945) observed a heavy growth of dinoflagellates in the highly polluted regions of the Oslofjord. Braarud and Pappas (1951) later found that the addition of small amounts of raw sewage to the medium stimulated the growth of Peridinium triquetrum." [p. 393.]

The author suggested that growth of dinoflagellates may be dependent upon, or at least benefited by, the previous flowering of diatoms. This he suggested (citing Pearsall, 1932, and Hutchinson, 1944) as possibly caused by the reduction of the concentrations of one or more of the nutrients or trace metals by diatoms to a level favorable for dinoflagellates. On the other hand, Lucas (1947, 1949) proposed that the production of external metabolites, or "ectocrines" by one group of plankton organisms may benefit the succeeding population, but inhibit competing organisms.

"The dinoflagellates . . . possessing the advantage of motility, are able to maintain themselves in water of low density with comparative ease and are relatively independent of vertical mixing. . . . [p. 395.]

". . . motility provides the dinoflagellates with an advantage in waters of low nutrient content. The nonmotile diatoms are dependent upon the dissolved nutrients contained in the water which immediately surrounds them and through which they sink (see Munk and Riley, 1952). In contrast, the dinoflagellates, though not strong swimmers, can move about for considerable distances and localize in the most advantageous depth for photosynthesis. If the nutrient level of the water is low, they may, by their vertical migrations, utilize all the nutrients available within the entire photic zone. According to Peters (1929) Ceratium can move through 5 to 10 meters in 12 hours or less." [p. 397.]

The report contains an extensive table of 21 red-water occurrences in various parts of the world, including some that caused mass mortalities. The author stated, ". . . one factor which is almost universal in red water outbreaks, the occurrence of a high water temperature. In temperate or boreal regions of the ocean, red water appears to be restricted to the summer months, and the notation is frequently made that it is preceded by periods of unusually hot, calm weather. Along the Indian coast, red water occurs during the clear, hot periods between the southwest and the northeast monsoons (Hornell and Nayudu, 1923; Menon, 1945; Bhimachar and George, 1950). Off the Peruvian and Southwest African coasts it appears during the southern summer

when the upwelling of cold water is at a minimum and water temperatures are the highest of the year (Brongersma-Sanders, 1948). . . . [p. 401.]

. . . . .

". . . there may be insufficient nutrients normally present in sea water, and no known mechanism for concentrating them to a sufficiently high level, to support the development of a typical red tide. The remaining possibility, that the organisms themselves become concentrated after growth, will be discussed below." [p. 403.]

The author here discussed at length, with much controversial documentation, the vertical migration of dinoflagellates and how light and buoyancy can affect it. His evidence for surface concentration is sketchy (for only two species in 6 m. of water). He said the accumulation of buoyant organisms at the surface would be enhanced in the absence of vertical mixing of the water, and that most occurrences of red tide throughout the world were accompanied or preceded by periods of calm weather and smooth seas. He added that such conditions, together with the high temperatures which usually accompany them, may cause thermal stratification, giving additional resistance to vertical mixing.

Ryther suggested three means by which organisms accumulated at the surface of the water may be further concentrated:

"(1) Prevailing onshore winds: Surface water driven shoreward by prevailing onshore winds establishes a circular pattern, sinking at the waters edge and returning seaward at lower depths. Buoyant organisms will accumulate in windrows along shore or at the region of descent (Fig. 3).

"(2) Where brackish coastal water, particularly in the vicinity of river mouths, meets open ocean water, there is a mixing and sinking of the two water masses along a line of convergence. Both types of water flow toward this line, and buoyant organisms will accumulate at or near the convergence line, producing streaks of floating material (Fig. 4).

"(3) Convection cells: Wind-driven vertical convection cells may be established which rotate alternately clockwise and counterclockwise with their vertical axes perpendicular to the direction of the prevailing wind. Floating objects will accumulate in the region between the descending components of two such adjoining cells. Under these conditions parallel streaks of floating matter are produced (Fig. 5). (For a more detailed description of this process, see Langmuir, 1938; Stommel, 1949). [p. 406-407.]

. . . . .

"Thus there is no necessity to postulate obscure factors which would account for a prodigious growth of dinoflagellates to explain red water. It is necessary only to have conditions favoring the growth and dominance of a moderately large population of a given species, and the proper hydrographic and meteorological conditions to permit the accumulation of organisms at the surface and to effect their further concentrations in localized areas." [p. 409.]

RYTHER, J. H., and R. R. L. GUILLARD.
1962. Studies of marine planktonic diatoms. II. Use of *Cyclotella nana* Hustedt for assays of vitamin B_{12} in seawater. Canad. J. Microbiol. 8(4): 437-445.

SALSMAN, G. G., and W. H. TOLBERT.
1963. Surface currents in the northeastern Gulf of Mexico. Navy Mine Defense Lab., Panama City, Fla., Rep. 209, 43 p.

SATER, EDNA N.
1954. Florida's red tide problem. Fish Wildl. Serv., Fish. Leafl. 420, 11 p.

This leaflet reviews generally the red tides from 1946-54 and research by Federal, State, and private agencies.

The theory is discounted that alleged dumping of war munitions brought about the kill of fish in 1946 and 1947.

"Red tides occur on the west coast of Florida only when certain peculiar conditions prevail: after a period of abnormally heavy rainfall followed by a shift from offshore to onshore winds. These circumstances lead to the accumulation of a mass of water of abnormally low salinity, which is kept from dispersing seaward by the winds blowing toward shore. In this water mass, the organism *G. brevis* explodes into what biologists call a bloom (an extraordinary increase in numbers), and becomes poisonous to fish life. As the fish die, their decaying bodies release nutrients which nourish the bloom and intensify it. [p. 6.]

. . . . .

"The theory is now held that the red-tide organisms are able to multiply

rapidly because nutrients are received through drainage from the land. . . ." [p. 7.]

In 1948, a small Federal laboratory was established at Sarasota, where laboratory culture experiments and hydrographic sampling at sea were undertaken. While the laboratory was at Sarasota, from 1948 to 1952, however, not one specimen of G. breve was taken in samples. The laboratory moved back to Galveston in June 1952, and the red tide broke out again in November.

Bureau scientists were able to keep G. brevis cultures alive after the 1952 outbreak. The Alaska collected a great deal of hydrographic data in the red-tide area, however, and had some success at killing red-tide organisms by discharging a concentrated solution of copper sulfate from its ballast tanks into the affected areas.

Another outbreak followed in September 1953. "During this outbreak, copper-sulfate crystals were placed in sacks and towed behind small boats, off Anna Marie Key, at the mouth of Tampa Bay. Again this experiment was successful in killing the organisms. . . . [p. 8.]

. . . . .

"From 1948 the Federal Government spent approximately $50,000 each year on red-tide research, until 1953 when the appropriation was reduced to $35,000. In the fiscal year 1955, $70,000 has been earmarked for the Fish and Wildlife Service's use. In January 1954, the Service reestablished a field station in Florida, this time at Fort Myers . . . .

. . . . .

"In May, a new 43-foot vessel, since named the Kingfish, was delivered at Fort Myers for use in studying the ocean conditions that cause red tides. . . . [p. 9.]

. . . . .

". . . the Gulf States Marine Fisheries Commission, established by a compact among the five Gulf States, has appointed a special red-tide committee, of which Dr. F. G. Walton Smith, Director of the University of Miami Marine Laboratory, is chairman. On the committee are representatives of the University of Florida at Gainsville and of the Fish and Wildlife Service, by law the primary research agency of the Gulf States Marine Fisheries Commission. The work of the three agencies is thus coordinated. . . ." [p. 10-11.]

SCHILLER, JOS.
1933. Dinoflagellatae. In Kryptogamen-Flora (L. Rabenhorst). Band 10, Abt. 3, Teil 1. Akad. Verlags., Leipzig, 617 p.

SCHILLER, JOS.
1937. Dinoflagellatae. In Kryptogamen-Flora (L. Rabenhorst). Band 10, Abt. 3, Teil 2. Akad. Verlags., Leipzig, 589 p.

SEYDEL, EMIL.
1913. Fischsterben durch Wasserblüte. Mitt. Fisch.-Ver., Prov. Brandenburg, N.F. 5(9):87-91.

SHERWOOD, GEORGE H., and VINAL N. EDWARDS.
1902. Red tide in Narragansett Bay, R.I. In Biological notes no. 2 (a contribution from the U.S. Fish Commission Biological Laboratory, Woods Hole, Mass.), p. 30. U.S. Fish Comm., Bull. 21.

SHILO, MOSHE, S. SARIG, MIRIAM SHILO, and H. ZEEV.
1954. Control of Prymnesium parvum in fish ponds with the aid of copper sulfate. Bamidgeh, Bull. Fish Cult. Israel 6(3): 99-102.

SHILO [SHELUBSKY], M., and M. ASCHNER.
1953. Factors governing the toxicity of cultures containing the phytoflagellate Prymnesium parvum Carter. J. Gen. Microbiol. 8(3):333-343. [Reference from Ray and Wilson, 1957.]

Concerning this paper Ray and Wilson (1957, p. 488) stated: "Another role for which bacteria must be considered is that of a detoxicating agent. Shilo and Aschner (1953) found that bacteria decreased the toxicity of cultures of Prymnesium parvum, a marine and brackish water chrysomonad that is toxic to fish. Similarly, bacterial activity may influence the toxicity of G. brevis in the laboratory and in nature." See also McLaughlin (1956).

SLOBODKIN, L. BASIL.
1953. A possible initial condition for red tides on the coast of Florida. J. Mar. Res. 12(1):148-155.

A minimum critical size is assumed for a water mass physiologically suitable for the growth of a phytoplankton

population, which will permit an increase in the concentration of organisms. It is also stated, however, that this relation is not of particular significance if the phytoplankton species in question is tolerant of a wide range of environmental conditions. The basis used to assume intolerance is two personal communications, one from Luigi Provasoli stating that G. breve is not generally amenable to culture techniques, and the other from Herbert Graham stating that G. breve is not normally found in the marine phytoplankton of the region. We do not accept these two premises. Furthermore, the assumption that red tide is found in very discrete water masses is at variance with the statement of most field observers that red tide water occurs in streaks, not in regular-shaped masses.

As confirmation of his theory, Slobodkin mentioned red discoloration of the sea observed at lat. 28°30' N. and long. 84°30' W. from the vessel Alaska on June 2, 1952. He stated, ". . . This discoloration was caused by a dense population of a red ciliate, probably Mesodinium pulex Noland or a closely related form (Kudo, 1947). The surface salinity at a hydrographic station in the discolored water (33.4‰) was lower than that at surrounding stations (34.99, 35.47, 36.17). This would seem to confirm the theory in so far as protista in general are concerned, since the discolored water was approximately 90 miles from the nearest coast." [p. 149, 151.]

To these reviewers this is not confirmed by the data of the Alaska (Collier, 1958a). The station referred to was located at lat. 28°30' N. and long. 84°32' W. (station 36). We have prepared a table showing pertinent data for this and the "surrounding" stations, including the three (Nos. 35, 38, and 40) to which Slobodkin referred. The nearest station was about 40 miles distant. It may be noted further that two of the three salinities to which he referred were not at the surface but at 10 m. Furthermore, at the station in question (No. 36), the salinity changed (?) from 33.42 to 33.48 p.p.t. in 42 minutes.

1952	Hour	N. Lat.	W. Long.	Salinity		Sta. No.	Approx. miles from sta. 36
				Surface	10 meters		
June 2	1901	28°30'	84°32'	33.42	35.29	36	0
June 2	1943	28°30'	84°32'	33.48	35.34	36A	0
June 2	1426	28°07'	85°50'	-----	36.17	35	40
June 3	0830	29°15'	84°46'	35.47	35.63	38	60
June 3	1829	28°33'	86°06'	33.36	34.99	40	100
June 3	1307	28°54'	85°25'	33.35	34.45	39	60
June 3	0324	29°13'	84°02'	34.94	35.53	37	60
June 2	0008	27°28'	85°23'	36.40	37.30	34	80
June 2	0357	27°05'	85°40'	36.13	36.13	33	100
June 1	2251	27°08'	[illegible]	36.24	36.10	32	90
June 1	1517	27°17'	84°11'	33.24	34.69	31	80
June 1	1011	27°24'	83°26'	34.83	35.25	30	80

Slobodkin continued, "On the basis of this evidence it can be stated tentatively that red tides require a discrete mass of water of relatively low salinity, but this does not imply that salinity difference is the sole requirement for red tides. . . ." [p. 151.] He then gave the following table of red-tide outbreaks:

"TABLE I(a).--Date and Location of Red Tide off the Florida Coast, and Associated Rainfall

Year	Date of Initial Report	Location of Red Tide	Rainfall (inches), Month; Weather Station
1844	Unknown (Ingersoll, 1882)	Tampa Bay	15.79, August; Tampa
1854	Unknown (Ingersoll, 1882)	Tampa Bay	15.5, July; Tampa
1878	September (Jefferson, et al., 1878)	Florida Bay	9.40, August; 25.10, September; Miami
1880	August (Ingersoll, 1882)	Tampa Bay	6.40, July; 14.00, August; Tampa
1882	July 20 (Anonymous, 1882)	Mouth of Tampa Bay	5.28, June; 10.44, July; Tampa
1883	Reported by Brongersma-Sanders (1948) from Walker (1884). Reference to Walker's original paper shows that these authors refer to the same 1880 outbreak. Walker's paper was submitted for publication under date of December 21, 1880.		
1885	October (Glennan, 1886)	Egmont Key to Charlotte Harbor	10.64, September; 1.95, October; Tampa 13.68, September; Manatee

TABLE I(a)--Continued

Year	Date of Initial Report	Location of Red Tide	Rainfall (inches), Month; Weather Station
1908	Reported by Taylor (1917) as killing sponges, without any mention of dead fish. This is probably an outbreak of sponge blight rather than red tide (Smith, 1941).		
1916	October 3 (Taylor, 1917)	Boca Grande to San Carlos Bay	12.56, July; 8.22, August; 5.34, September; Fort Myers
1946*	November 20 (Gunter, et al., 1948)	Naples	9.23, September; 2.03, October; 9.69, November; Naples
	In October 1946, Fort Meyers, Punta Gorda and the Everglades, Florida were flooded by unusual tides in the wake of a hurricane on October 7-8. Charlotte Harbor and part of the Everglades can be considered as having been thoroughly mixed with sea water, which drained into the Gulf of Mexico in considerable volume. November was warmer by 6.1° than any previous November on record (71.2° mean for Florida). October was 1.1° above normal and warmer than any October in five years for the state as a whole.		
1947*	March (Gunter, et al., 1948)	Florida Bay	10.37, March; Captiva 8.94, March; Fort Meyers Greatest March rainfall on record for state with exception of 1930
1947*†	June 20 (Gunter, et al., 1948)	Bonita Beach (South of Fort Myers)	6.47, May; 12.84, June; Fort Myers (2.69 inches fell after June 20) 3.34, May; 13.33, June; Punta Gorda (.04 inches fell after June 20)
1947*†	July 18 (Gunter, et al., 1948)	Venice to Sarasota	13.06, June; 11.44, July; Sarasota (7.64 inches after July 18) 18.25, July; Punta Gorda (12.72 after July 18) Floods in Okeechobee region during June and July
1952	October 25	Boca Grande and Southwest of Sanibel	12.35, September; 8.34, October; Fort Myers (none after October 25)

*All outbreaks marked with an asterisk are considered by Gunter, et al. (1948) as representing a single occurrence. Since discoloration and fish mortality disappeared between each of the listed dates, they are here considered as separate.

†The interval with no fish kills separating these two outbreaks is of the order of two weeks and may or may not indicate separate dinoflagellate populations."

Slobodkin then presented a table for comparison with table I (a) above.

"TABLE I(b).--Mean Rainfall (inches) by Months at Five Florida Weather Stations

	J	F	M	A	M	J	J	A	S	O	N	D	Years
Belle Glade	1.68	1.48	2.70	2.33	3.60	9.01	6.90	8.06	7.41	4.84	2.90	1.32	1924-1951
Fort Myers	1.76	2.02	1.89	1.89	4.13	8.91	8.16	8.82	7.45	4.48	1.33	1.56	1851-1951
Miami	2.27	2.03	2.63	3.41	7.15	7.07	5.60	5.88	8.65	7.74	3.26	1.98	1855-1951
Punta Gorda	2.24	1.83	2.21	2.20	3.61	7.48	7.54	8.05	8.22	3.97	1.56	1.85	1914-1951
Tampa	2.69	2.56	2.33	2.01	2.99	7.25	7.95	8.18	6.42	3.19	1.72	2.07	1840-1951"

SMITH, F. G. WALTON.

1949. Probable fundamental causes of red tide off the west coast of Florida. Quart. J. Fla. Acad. Sci. 11(1):1-6.

The theory is advanced that the red-tide blooms must depend upon unusual amounts of phosphorus. The origin of such phosphorus could be deposits in river drainages or offshore deposits but the manner of dispersal remains a mystery deserving investigation.

SMITH, F. G. WALTON.

1954. Emergency report on the Florida red tide, January 1954. Univ. Miami, Mar. Lab., Rep. to Fla. State Bd. Conserv., Tech. Rep. 54-2, 4 p.

This report summarizes the status of red-tide research by the Marine Laboratory as of January 1954. It names Gymnodinium brevis as the causative organism of the Florida red tide, and says that red tide occurs sporadically; damage to commercial fisheries in a bad red-tide year exceeds $1 million; Gymnodinium brevis releases fish-killing poisons into the water; phosphorus compounds are necessary for plankton growth; other factors besides phosphorus are necessary for the red tide; attempts to establish correlations with meteorological phenomena were unsuccessful; and laboratory culturing of Gymnodinium provided information on special nutrient requirements.

The author believed that destruction of the bloom serves little purpose and that the only solution is the prevention of blooming.

A 2-year program at a cost of $72,000 per year is outlined to ensure successful prediction, prevention, and control of red-tide blooms. This program entails:

"(a) Full-time year-round oceanographic investigation of the chemical and physical changes of the West Coast waters.

"(b) Multiple statistical correlation of outbreaks with meteorological and other ambient phenomena.

"(c) Tropistic and nutritional laboratory studies of the causative organism." [p. 4.]

The author stated that the greatest success will be obtained by providing adequate funds which "should be concentrated in one locality or organization, equipped with proper laboratory facilities and oceanographic vessels, and with personnel experienced in the Red Tide problem." [p. 4.]

SMITH, F. G. WALTON.

1957. Mystery of the red tide. Smithsonian Inst., Annu. Rep. for 1957:371-380.

This is a semipopular article without documentation, apparently largely a reprint from Sea Frontiers 3(1):21-31. Some of the illustrations appeared in Galtsoff (1949).

On page 373 it mentions "as many as 60,000,000 individual cells to the pint of water" but we are sure this is merely an error in transposing a liter into an English equivalent.

". . . Since 1947 red tide seemed to have disappeared and there was no way of telling whether it might return in 1 year or 10 years. . . . [p. 376.]

. . . . .

"These expectations were partly realized in 1952 when a fresh but minor outbreak occurred. About the middle of September 1953 further red tide was reported and this continued at intervals throughout the winter and in the spring and summer of 1954. The new alarms brought special funds to aid research at Miami and increased federal activity. The State of Florida made a wise move by setting up a Red-Tide Committee in order to coordinate research activities. . . .

"Materials are needed for the growth of 'Jim brevis' and the suspicion that the brackish bay waters contained some essential part of these materials received new attention as the result of work carried out by the Haskins Laboratory in New York. For the first time the red-tide type of organism was kept alive in the laboratory in a pure culture, uncontaminated by bacteria or other organisms. . . ." [p. 377.] (Reviewers' note: These were dinoflagellates other than G. breve, which was first cultured in a pure state at Galveston by the Fish and Wildlife Service.)

". . . after taking meteorological figures for 26 past years and performing numerous calculations with different combinations of the data, a formula emerged which worked. The weather information for any year was placed into the formula. When the numerical result fell within a certain narrow range, then a red-tide outbreak happened during the next 12 months. If outside the range, there was no red tide.

". . . In November 1955 the State Board of Conservation in Florida was notified that there was little likelihood of major red-tide outbreaks in the year

1956. It turned out that there was none. A similar prediction was made for 1957. . . ." [p. 379.] (Reviewers' note: A heavy outbreak occurred in 1957.)

SOLI, GIORGIO.
1964. A system for isolating phytoplankton organisms in unialgal and bacteria-free culture. Limnol. Oceanogr. 9(2): 265-267.

SOMMER, HERMANN, and FRANCES N. CLARK.
1946. Effect of red water on marine life in Santa Monica Bay, California. Calif. Fish Game 32(2):100-101.

During June 1945, red water occurred from San Luis Obispo to Los Angeles Harbor. On June 19 dead fish and shellfish--chiefly spiny lobsters, Panulirus interruptus--were observed in Santa Monica Bay. Also affected were spider crabs and many fishes, including halibut, stingrays, and sharks. Ceratium was suspected as the cause but proof was not definite.

SOMMER, HERMANN, W. F. WHEDON, C. A. KOFOID, and R. STOHLER.
1937. Relation of paralytic shell-fish poison to certain plankton organisms of the genus Gonyaulax. Arch. Pathol. 24(5): 537-559.

SPECHT, R. C.
1950. Phosphate waste studies. Fla. Eng. Ind. Exp. Sta., Bull. 32, 27 p.

Figures are given showing the phosphate content of the Peace and Alafia Rivers to be very high.

SPENCER, C. P.
1952. On the use of antibiotics for isolating bacteria-free cultures of marine phytoplankton organisms. J. Mar. Biol. Ass. U.K. 31(1):97.

STARR, THEODORE J.
1956. Relative amounts of vitamin B_{12} in detritus from oceanic and estuarine environments near Sapelo Island, Georgia. Ecology 37(4):658-664.

Mentions B_{12} found in bottom mud.

STARR, THEODORE J.
1958. Notes on a toxin from Gymnodinium breve. Tex. Rep. Biol. Med. 16(4): 500-507.

Starr described procedures for the bioassay of the toxin in unialgal cultures of G. breve and some properties of crude toxin preparations.

Toxin was prepared from cultures of 1.5 million living cells of G. breve (at a pH of 8.15, salinity 33 p.p.t., 7 weeks old) frozen overnight in flasks, thawed at room temperature (25+ 2° C.) and filtered through an AA millipore filter. Dilutions were made with seawater medium of 33 p.p.t., pH of 7.9.

Preliminary experiments with guppies and mullet indicated that living cultures of G. breve were less toxic than killed ones. The toxin preparation was tested on mullet at several dilutions and the results were shown in a curve. If we interpret his curve in numbers of G. breve per liter needed (when killed) to produce the effect, the results are approximately:

No. of cells	Average time of death
1,500,000	2 to 4 minutes
450,000	under 30 minutes
300,000	over 50 minutes
150,000	4 to 8 hours, sometimes failed to kill

Residues (cell debris) left on AA millipore filters contained little or no toxicity. Heat had an effect on toxicity of the cell-free toxin preparation. When heated and cooled immediately in an ice bath, little toxicity was lost from heating to 80° C., but most of the toxicity was lost from heating to 100° C.

Heating over longer periods destroyed toxicity at lower temperatures. Thus, most of the toxicity was lost by heating to 45° C. for 4 hours, and no toxicity was detected after heating to 100° C. for 5 minutes.

Toxicity of living unialgal cultures was increased by pH of 8.1 (5-weeks-old culture, salinity 30 p.p.t., 1.2 million per liter) being changed by adding 5N HCl or 5N NaOH to the media. At pH 3.3, 5.4, and 9.5, G. breve were destroyed and toxicity was, thus, increased. Changes in pH of cell-free toxin had little or no effect on toxicity. Adding sufficient heavy metals to kill G. breve increased the toxicity of unialgal cultures.

STOHLER, R.
1960. Fluctuations in mollusk populations after a red tide in the Estero de Punta Banda, Lower California, Mexico. Veliger 3(1):23-28. [Cited from Biol. Abstr.]

A collection of mollusks made during the peak of a red tide in 1958 was compared with collections made in July

1959 and January 1960. It was concluded that neither red tide nor seasonal variations could be held responsible for the fluctuations observed in sizes and occurrence of specimens.

STOMMEL, HENRY.
1949. Trajectories of small bodies sinking slowly through convection cells. J. Mar. Res. 8(1):24-29. [Cited by Ryther, 1955.]

Explanation of the accumulation of floating objects in windrows parallel to the wind direction by wind-driven convection cells.

STREETS, THOS. H.
1878. The discolored waters of the Gulf of California. Amer. Natur. 12(1):85-90.

STRODTMANN, S.
1898. Ueber die vermeinte Schädlichkeit der Wasserblüte. Forschungsber. Biol. Sta. Plon. 6(9):206-212.

SWEENEY, BEATRICE MARCY.
1951. Culture of the dinoflagellate *Gymnodinium* with soil extract. Amer. J. Bot. 38(9):669-677.

Soil extracts have been widely successful in promoting the culture of organisms difficult to grow in inorganic media. The active principle in soil extract according to Pringsheim (E. G. Pringsheim, 1936, Das Ratsel der Erdabkochung. Beih. Bot. Centralblatt A55:101-121) in experiments using *Chlorogonium*, *Polytoma*, *Polytomella*, and *Chilomonas* is an acid- and alkaline-stable organic substance, insoluble in alcohol and ether, adsorbed by charcoal, and destroyed by hydrogen peroxide.

Gymnodinium splendens was cultured in several media, usually in inorganic media with organic additives. No inorganic additives aided growth. Soil extract promoted growth. The soil extract was made from redistilled water and garden soil, which was autoclaved, decanted after standing overnight, and reautoclaved. Although presumably bacteria-free, the soil extract was of little or no avail when first prepared; it reached a peak of activity (in promoting growth) in 4-6 weeks and declined in activity after about 80 days. Activity of soil extract was not retained by reautoclaving or by refrigeration at 4° C. Deep freezing at -25° C. preserved activity for 6 months. Trials of additions of several different amino acids, yeast extract, oak leaf mold extracts, etc., were unsuccessful.

The only other active principle came from cells of another dinoflagellate, *Prorocentrum micans*, also grown in 4 percent soil extract.

SWEENEY, BEATRICE M.
1954. *Gymnodinium splendens*, a marine dinoflagellate requiring vitamin B_{12}. Amer. J. Bot. 41(10):821-824.

SWEENEY, BEATRICE M., and J. WOODLAND HASTINGS.
1958. Rhythmic cell division in populations of *Gonyaulax polyedra*. J. Protozool. 5(3):217-224.

"In cultures of the marine dinoflagellate *Gonyaulax polyedra* grown with alternating light and dark periods of 12 hours each, at least 85% of all cell divisions which occur in a day take place during a 5-hour period spanning the end of the dark period and the beginning of the light period. A very distinct maximum in the number of recently divided cells occurs at about the time the light period begins.

"This diurnal periodicity in cell division is lost after 4 to 6 days in continuous bright light, but will persist for at least 14 days in continuous dim light. The period of approximately 24 hours under constant conditions is only slightly altered by varying light intensity and temperature, both of which factors are known to affect markedly the generation time. The time at which cell division occurs is therefore postulated to be controlled by some sort of rhythmic or clock mechanism.

"Similarities between the cell division rhythm and the endogenous rhythm of luminescence in this organism are discussed. The occurrence of a glow, or steady light emission of low intensity, at about the time of cell division, is described, and it is suggested that this glow may result from cellular changes accompanying certain stages of cell division." [p. 217.]

TABB, DURBIN C., and DAVID L. DUBROW.
1962. Hydrographic data, Supplement I, from the inshore bays and estuaries of Everglades National Park, Florida, 1959-1962. Univ. Miami, Mar. Lab., Rep. to Fla. State Bd. Conserv. 62-9, 22 p.

Includes temperatures, salinity, oxygen, and pH.

TABB, DURBIN, DAVID DUBROW, and RAYMOND MANNING.
1959. Hydrographic data from the inshore bays and estuaries of Everglades National Park, Florida, 1957-1959. Univ.

Miami, Mar. Lab., Rep. to Fla. State Bd. Conserv. 59-5, 26 p.

TAYLOR, HARDEN F.
1917a. A mortality of fishes on the west coast of Florida. Science 45(1163):367-368. [Cited from Gunter, 1947.]

TAYLOR, HARDEN F.
1917b. Mortality of fishes on the west coast of Florida. Rep. U.S. Comm. Fish. for 1917, append. 3, 24 p. (Doc. 848.)

". . . The reports and references are too fragmentary to give an accurate record . . . but collectively they clearly indicate that all the keys from Key West nearly as far north as Cedar Keys have been visited by this plague, and that it occurred in the years 1844, 1854, 1878, 1880, 1882, 1883, 1908, and finally in 1916.

"In October and November, 1916, the mortality recurred in severe form, the first visitation since 1908. . . .

"Fishes of a great number of species were noted dead and dying; the air was charged with a suffocating gas, which . . . irritated the air passages, producing the symptoms of colds. This gas, while exceedingly irritating, had no odor. . . . The abnormal conditions seemed to be moving southward, occurring at Boca Grande on October 3 and 18, at Captiva Pass about the middle of October, at Blind Pass about October 20, at San Carlos Pass about November 1, and dead fish were first seen at Big Marco Pass on November 5. Captiva Pass is 7.5 statute miles south of Boca Grande Pass; the others are, respectively, 16.5, 27.75, and 67.75 miles to the south of Boca Grande Pass. . . . dead fish were seen as far south as Cape Romano. . . . The death of two persons in Fort Myers, Fla., in November, was attributed to the eating of some of these dead fish." [p. 5-6.]

He quoted a letter from the deputy collector of customs at Boca Grande stating that the dead fish started to come ashore on October 3. In a few days the plague abated, but another violent outbreak occurred on the 18th, killing larger fish and many of the bay fishes. The gas was worse, and many people asked for medical assistance.

Taylor listed 63 species of fish killed and sea urchins (Arbacia), horseshoe crabs, and sponges. He said barnacles, oysters, and mussels were in good condition, live conchs and hermit crabs were observed repeatedly, porpoises were plentiful, and pelicans and other water birds behaved normally. Buzzards were common but neglected the fish entirely.

". . . at the height of the mortality, on the Gulf coast, the water was of an amber color (by transmitted light). This colored water was described as being not uniformly distributed, but occurring in streaks, and it was in these streaks that the fish are said to have perished. . . ." [p. 11.]

TORREY, HARRY BEAL.
1902. An unusual occurrence of Dinoflagellata on the California Coast. Amer. Natur. 36(423):187-192.

Bloom was first noted on July 7, 1901, as a red streak off the mouth of San Pedro Harbor. He identified it as Gonyaulax and mentioned an unusual display of phosphorescence. The "muddy vermilion" streak reached the shore on the 16th. On the 20th the beach (about 400 yards long) was lined with dead animals--several hundred holothurians, stingrays, guitarfishes, sharks, red perch, smelts, and several octopi.

The "red water" occurred for 200 miles, from Santa Barbara to San Diego, and extended several miles to sea. It was still present around San Pedro on September 1.

". . . Noctiluca appeared in great numbers toward the end of July, and devoured Gonyaulax with avidity. . ." He mentions nine additional species of dinoflagellates present in lesser abundance. The red water was not present at Santa Catalina Island, 20 miles offshore.

"The boundaries of the red streaks were quite sharply marked, although the water between streaks often contained Gonyaulax. . ." [p. 191.]

U.S. FISH and WILDLIFE SERVICE.
1958. Red tide symposium, Galveston, Texas, March 5-7, 1958. 72 p.

U.S. FISH and WILDLIFE SERVICE.
1961. The Florida red tide. U.S. Fish Wildl. Serv., Fish. Leafl. 506, 8 p. [Revision of FL 420.]

During the 1946-47 outbreak:--"Practically all species of fish, including such large forms as tarpon and jewfish, were included in the victims of the red water. Most oysters in affected areas died. Horseshoe crabs died by the thousands, but true crabs apparently were unharmed. Sponges showed no ill effects (the principal sponge beds near Tarpon Springs were outside the Red Tide area). [p. 2.]

. . . . .

"In 1953, Red Tide organisms at the Galveston Laboratory were first cultivated artificially. . . ." [p. 6.]

UNIVERSITY OF MIAMI, MARINE LABORATORY.

1954. Red tide studies, January to June 1954. Prelim. Rep. to Fla. State Bd. Conserv. 54-19, 117 p.

This report covers many aspects of red-tide research carried out by the Marine Laboratory, but also summarizes research by other agencies, without specifically mentioning under whose auspices the work was accomplished. Despite an occasional reference to an outside author, there is no bibliography or list of references cited. Because of this lack of documentation and a list of 19 personnel (total of only 866 man days, including boat operations), the report is clearly intended (as the title indicates) as merely a progress report. It is stated that, "This report is a preliminary account of the results. Because of the emergency nature of the Red Tide problem, and, in order that the data may become immediately available to other workers in the field, it has been prepared for a restricted distribution without the careful evaluation normally given to scientific reports. For this reason it is in many ways incomplete and all discussions and conclusions must be considered as tentative in nature, subject to re-evaluation as the data receives more careful scrutiny." [p. 3.]

The report starts with a summary:

"4. In the course of the work a survey was made of the scientific literature concerning plankton blooms throughout the world." [p. 1.] This survey has not been published.

"5. . . . The initial series of fish kills constituting a Red Tide cycle were found to occur most frequently in the month of October and within the dates of the new moon plus or minus three days." [p. 1.] This conclusion is not accepted by us as having been proved.

"A cycle or series of outbreaks is mostly likely to occur when the annual rainfall of the Peace River drainage area is above the fifty year average. A correlation also exists between outbreaks and a high maximum annual discharge of the Peace River." [p. 1.] No actual statistical analysis is shown, and the best example shown of high rainfall, in 1947, gives a false impression since the 1947 outbreak really started in November 1946, after a long dry spell, and quit in September 1947, during the heaviest rainfall.

"6. The results of hydrographic studies carried out in previous years had demonstrated the presence of Red Tide at the interface between Gulf and Bay waters. Attempts were made to develop further these relationships, but no evidence was found to substantiate the idea of a more or less continuous front between Gulf and Bay waters along which the Red Tide progresses. It now seems far more probable that a periodic separation of masses of Bay water susceptible to Red Tide takes place at the mouth of the passes and that these masses move with prevailing currents, usually northward, slowly losing their identity by mixing and diffusion with the Gulf Water." [p. 1-2.] We do not accept this latter theory (see Chew, 1953).

"7. . . . initial fish kills are most active and . . . G. brevis blooms most often originate at the inner side of such passes as Boca Grande. . . ." [p. 2.]

"10. A study of commercial fish landings fails to reveal any significant decrease in the commercial catch in relation to Red Tide. . . . [p. 2.]

"12. It is strongly recommended that advance planning be undertaken for the control of Red Tide should outbreaks occur in the fall of this or future years. The most practical method of alleviating the damage is considered to be by seining of dead fish while concentrated in the passes and at sea, before drifting on the beaches.

"It is considered that chemical control is more expensive and less likely to be successful than the control of dead fish by seining. Nevertheless, it is recommended that chemical treatment be applied at the passes at the earliest possible moment of a Red Tide outbreak in order to evaluate its usefulness." [p. 2.] Concerning treatment in passes see Ingle et al. (1959).

"13. . . . it is suggested that attention be paid to the possibility of modifying the nutrient conditions of the Bay waters in such a way as to prevent Red Tide conditions from developing. A large scale fish culture program in the Bays, with the addition possibly of supplementary nutrients other than phosphorus might conceivably be brought about. Under these conditions the nutrient regime and the food chains might conceivably be changed so as to minimize the development of conditions suitable to Red Tide." [p. 2.]

On page 3 it is stated that "During the 1947 outbreak, scientists of the

Marine Laboratory of the University of Miami established that the fish mortality and the irritant gas associated with it were due to a plankton bloom. . . ." Woodcock (1948), from the Woods Hole Oceanographic Institution, established this connection between red tide and the irritant gas carried as an aerosol.

On page 7 it is stated, "The theory of submarine springs as a possible indirect cause for the Red Tide has been tested; however, the results, so far, seem to show that this explanation is not correct." There is no explanation of what "test" was applied.

"The annual phosphate production (land pebbles) statistics were studied. No correlation was found between year to year fluctuations in the phosphate production and the outbreaks of Red Tide." No data are presented.

". . . By means of the method of least squares it was found that the total phosphorus content in the Peace River water is around 31 and in the Caloosahatchee River around 6 microgram atoms/L. . . ." The "method of least squares" is a method usually used for curve fitting and can hardly have a bearing on calculation of a mean value. Graham et al. (1954) obtained average total phosphorous values of 12.0 and 2.6 ug.at./l. for the Peace and Caloosahatchee Rivers. On page 23 of the Marine Laboratory report it is stated that out of 22 stations on the Peace River, the maximum amount of total phosphorus was close to 32 ug.at./l., near phosphate quarries. It would appear that the average derived by "least squares" of 31 ug.at./l. is unrealistic.

About 4 pages of the report list notes on red-tide outbreaks chronologically from September 1952 through July 1954. On September 24, 1953 is the cryptic note, "Tried $CuSO_4$."

The report does not give the technique used for counting G. breve in the samples. However, we believe that their counts are far too high. For instance, they stated on p. 73, ". . . With one exception, no discoloration was found in which less than 15,000,000 cells/L. occurred. . . ." This was entirely at variance with our experience during the 1957 outbreak, when it was easily possible to guide spray planes onto patches of red tide containing only a few million cells per liter.

". . . What appeared to be resting stages of G. brevis were found in salt water muds. These clearly resembled the forms which appear when G. brevis is partly dessicated. Attempts to convert the suspected forms to the identifiable motile stage were unsuccessful.

. . . . .

"It was frequently noted that even when no other organism was present, a bloom of G. brevis contained large numbers of the copepods Acartia sp. . . ." [p. 74.]

UNIVERSITY OF MIAMI, MARINE LABORATORY.
1961a. A report of data obtained in Florida Straits and off the west coast of Florida, January-June 1960. Rep. to Off. Nav. Res., Tech. Rep. 61-1, 189 p.

A report containing raw hydrographic data obtained in an area north of Key West from Cape Sable to Dry Tortugas (January-June, 1960).

UNIVERSITY OF MIAMI, MARINE LABORATORY.
1961b. A report of data obtained in Florida Straits and off the west coast of Florida, July-December 1960. Rep. to Off. Nav. Res., Tech. Rep. 61-3, 109 p.

A report containing raw hydrographic data obtained in an area north of Key West from Cape Sable to Dry Tortugas (July-December, 1960).

UNIVERSITY OF MIAMI, MARINE LABORATORY.
1962a. A report of data obtained in Florida Straits and off the west coast of Florida (January-June 1961). Rep. to Off. Nav. Res., Tech. Rep. 62-4, 200 p.

A report containing raw hydrographic data obtained in an area north of Key West from Cape Sable to Dry Tortugas (January-June, 1961).

UNIVERSITY OF MIAMI, MARINE LABORATORY.
1962b. A report of data obtained in Florida Straits and off the west coast of Florida, July-December 1961. Rep. to Off. Nav. Res., Tech. Rep. 62-6, 108 p.

VEENHUYZEN, J. C.
1879. Communication: Trichodesmium erythraeum. Natuurk. Tijdschr. Ned. Indie 38:150-151. [Cited from Fish and Cobb. Non vidi.]

WALKER, S. T.
1884. Fish mortality in the Gulf of Mexico. Proc. U.S. Nat. Mus. 6:105-109.

On November 20, 1880, he sailed south through Boca Ciega Bay and encountered the first dead fish near Bird Key, a little southeast of Pass A'Trilla. On attempting to land on the extreme point of Point Pinellas he was

driven back to his boat by the stench of thousands of rotting fish upon the beach. He mentioned a large variety of dead fish and many he could not identify. He found the same species at Gadsden Point. He saw only a few dead fish at Tampa, principally gars and catfish. His summary is:

"1. The dead fish were most numerous on the outside beaches and on the inside beaches of the outer line of keys.

"2. That dead fish were least numerous about the mouths of creeks and rivers, decreasing gradually as one approached such places.

"3. That the poisoned water was not diffused generally, but ran in streams of various sizes, as proven by fish dying in vast numbers instantly upon reaching such localities.

"4. That the fish were killed by a specific poison, as proven by the sickness and death of birds which ate of the dead fish.

"5. The fish began dying on the outside beaches first, as Mr. Strand, assistant light-keeper at Egmont, reports them coming up first on the 17th of October, while Mrs. Hoy observed them first on the 1st or 2d of November, at Little Manatee River.

"6. The examination of many hundred recently-dead fish revealed no signs of disease. The colors were bright, the flesh firm, and the gills rosy. The stomach and intestines appeared healthy. [p. 106.]

"In my haste I have neglected to state that I saw a good many dead birds during the trip. At Tampa, ducks were dying. I saw dead vultures at Anna Maria Key, and at Passage Key, large flocks of cormorants were sick and dying. I also saw the carcasses of terns, gulls, and frigate birds. The cormorants sat on the beach with their heads under their wings, and could be approached and handled." [p. 106-107.]

He appended statements by several witnesses:

"The fish began dying about the last of October here [Point Pinellas] . . . When a school of mullet get into water covered by this black scum, they die at once. Oysters are affected by this also, and those who eat of them are made very sick.

"The oyster saloons here were obliged to close, as the oysters came near killing several people.

"The fish began dying here [Little Manatee] about the first of November . . . A few days after the fish began dying I had a quart of fine oysters for dinner." He and his daughter ate the oysters and were both sick, but a visitor and his servant who did not eat oysters were not affected.

Two men who owned a fishing smack with a live well stated, "The poisoned water runs in streaks, for often when three or four smacks are in company one or two will lose all their fish in a few minutes, while others, a short distance off, lose none."

The keeper of Egmont Light said first dead fish appeared on October 17, later ducks, and other sea birds.

WEBB, JOHN G.

1887. 5.--The mortality of fish in the Gulf of Mexico. U.S. Fish Comm., Bull. 6:11-13.

This reference is of no significance.

WENNEKENS, M. P.

1959. Water mass properties of the Straits of Florida and related waters. Bull. Mar. Sci. Gulf Carib. 9(1):1-52.

Gives a diagram of the general current system of the eastern Gulf.

WHITELEGGE, THOMAS.

1891. On the recent discolouration of the waters of Port Jackson. Rec. Aust. Mus., Sydney, 1(9):179-192.

A mass mortality caused by <u>Glenodinium rubrum</u> occurred in March 1890, at Port Jackson, Australia, during hot weather following heavy rainfall. The organism occurred in streaks or patches. It caused great devastation among oysters.

WILSON, WILLIAM B.

1955. Laboratory studies of <u>Gymnodinium brevis</u>. Address to American Association for the Advancement of Science, 14 p. [Mimeographed.]

In first attempts to culture <u>G. breve</u>, organisms failed to grow (reproduce ?) and reacted as though most media were toxic. Addition of a metal chelator (EDTA-Na) helped but still only 40 percent success was attained. The difficulty was chiefly with proper washing and sterilization of the test tubes.

Good growth resulted from 175 ft.-c. (foot-candles) for 15 hours per day, but not from 150 ft.-c. maintained continuously. Eight hours at 175 ft.-c. were insufficient. Cloud cover could be a limiting factor.

<u>G. breve</u> survived 1 hour at 34° C. but cytolized at 35° C. When temperature

is lowered at 2° per hour, they become immobile and cytolize between 12° and 14° C., but when lowered at 1° per hour they are active until they reach 8° to 10° C.

G. breve survive salinities from 24 to 40 p.p.t., but become inactive at 20 p.p.t. or 42 p.p.t. (90 to 100 percent of culture). Also see Aldrich and Wilson (1960).

G. breve survived pH from 7.0 to 8.6; growth was best from 7.3 to 8.1. A mature culture declining from its peak growth frequently reverts to the growth phase if one of several nutrients is added, namely: B_{12}, thiamine, biotin, phosphate, ammonia, a group of trace metals, or soil extract.

If fish autolysate is added to the original culture medium, it frequently stimulates excessive bacterial growth and the culture dies. In mass cultures which are cropped and new media added the highest concentration of G. breve is normally 4 million per liter, and never as high as 5 million. Fish autolysate added to a 3.5-million culture raised it to 9 1/2 million in 4 days but it fell to zero in 1 week.

The author believed there is a mutually beneficial relationship between G. breve and "the dominant bacterial contaminant of mass cultures." He says G. breve produce carbohydrates which could account for the increased bacterial growth, while bacteria produce vitamin B_{12} needed by G. breve.

In confirmation of this mutuality of interests the author had sealed cultures of G. breve and G. splendens that were maintaining themselves after 2 and 2 1/2 years, respectively.

The author could not subculture G. breve without adding soil extract to the medium. Ashed soil extract would not substitute, and neither would known chemicals. Soil extract dialyzate is not beneficial but the dialyzed portion remaining is beneficial, indicating organic compounds of high molecular weight.

Of several metals tested, copper was most toxic.

WILSON, WILLIAM B.

1958. Compounds toxic to red tide organisms. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 66-67.

Discusses progress on factors affecting the toxicity of copper to G. breve.

"Tests on the toxicity of fluorescine dye to G. breve indicated that it is not toxic in concentrations of 100 parts per million. These results indicate that fluorescine dye can be used as a marker in field experiments without altering the results." [p. 67.]

WILSON, WILLIAM B.

1959a. Evaluating toxicity of dissolved substances to microorganisms using dialysis membranes. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 100-102. U.S. Fish Wildl. Serv., Circ. 62.

To test the effects of copper in the field, known concentrations of Prorocentrum sp. were placed in bags made of dialysis membrane. The bags were suspended inside perforated polyethylene bottles for protection from macro-organisms.

". . . Between two and five hours were required for the inside concentration to approach 0.8 μg.at. Cu/l with an outside concentration of 1.6 μg.at. Cu/l. An outside concentration of 0.8 μg.at. Cμ/l did not raise the inside concentration to a comparable amount within 24 hours." [p. 101-102.]

WILSON, WILLIAM B.

1959b. Nutritional studies on red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 72-74. U.S. Fish Wildl. Serv., Circ. 62.

"The minimum calcium content of media in which G. breve grew was approximately one-sixth the amount of standard sea water (salinity - 35.5‰), or approximately 70 mg/l (1.7 mg at/l). An increase in calcium to twice the amount of open ocean water was not detrimental as long as the phosphorus content was less than 5 μg.at/l. If the calcium content is between 140 and 400 mg/l, cultures have grown very well in most concentrations of phosphorus. There was some limitation of growth if the phosphorus was less than 0.04 μg.at/l or more than 100μg.at/l. In the latter case, the high phosphorus content caused precipitation, as did excessive calcium. When precipitation occurred, G. breve did not grow.

"The results of the calcium-phosphorus experiments indicate that if the calcium concentration was the same as that of normal open ocean water (approximately 400 mg/l), inorganic phosphorus content should be 0.4 μg.at. per liter or greater for the medium to support good growth of G. breve. Optimum growth occurred within a range of

0.4 to 40 μg.at/l of phosphorus if the calcium content was between 140 and 400 mg/l. Media with phosphorus concentrations as high as 400 μg.at/l supported good growth of G. breve if the calcium concentration was between 140 and 250 per liter. On the other hand, media with calcium concentration as high as 1,000 mg per liter supported good growth if the phosphorus content was between 0.04 and 4.0 μg.at/l. The above values for calcium and phosphorus should be revised slightly upward (less than 0.01 percent) because of the occurrence of these elements as contaminants in the other components of the medium. [p. 72.]

"Vitamins. Three water soluble vitamins, thiamine (B_1), biotin (B_3) and cobalamin (B_{12}), have been used consistently in artificial sea water media for bacteria-free G. breve. Results of earlier experiments indicated that G. breve would not grow in these media unless these vitamins were added. In addition, thiamine was the most effective of the three vitamins, but a combination of thiamine and biotin supported better growth than thiamine alone. During the past year, a series of nine experiments was conducted to define more clearly the role of these vitamins in the growth of G. breve. [p. 72-73.]

"Results of these experiments are similar in many ways to the results of previous work in that thiamine was the most active of the three vitamins and a combination of thiamine and biotin was better than thiamine alone. However, these experiments indicate that the inclusion of cobalamin along with the thiamine and biotin further improved growth. In the earlier experiments, we had omitted cobalamin in ten serial subcultures without diminution of growth. In recent experiments, omission of cobalamin has resulted in lesser growth. To ascertain the source of the apparent discrepancy in these results we will initiate growth experiments using cobalamin and the other vitamins from more than one supply house. [p. 73.]

"The need for thiamine is pronounced in the experiments conducted to date. There is a possibility that similar organic compounds will substitute for thiamine and we plan to conduct experiments to determine if such is the case. If not, assays of this vitamin in the field may be valuable for forecasting red tides. [p. 73-74.]

"Trace elements. In earlier experiments we were unable to grow G. breve in artificial sea water media unless a group of trace elements was added. We have attempted to determine the elements of this group that are necessary for growth, but to date the results are inconclusive. Some elements, notably zinc, titanium, zirconium, and manganese and boron may be required by G. breve. The results of experiments using these as additives indicate that they may improve growth. Media containing copper, nickel, rubidium, molybdenum and barium have on occasions supported better growth than media to which they were not added. The addition of iron has not improved growth regardless of the concentration or form in which it was added. This does not mean that iron is not needed by the organism because it is a common contaminant of the major salts used in preparing the medium.

Effect of some vitamins and a group of trace elements on the growth of G. breve in artificial sea water medium (Numbers represent percent of cultures with each addition in each growth category)

Additives[1]	None to slight	Slight (less than 0.5)	Fair (0.5 to 1.0)	Good (more than 1.0)
No addition.......	100	0	0	0
B_{12}...............	100	0	0	0
B_1................	50	22	28	0
B_3................	92	2	4	2
T..................	100	0	0	0
B_1 and B_{12}........	50	20	30	0
B_3 and B_{12}........	70	4	26	0
T and B_{12}.........	72	6	22	0
B_1 and B_3.........	10	50	25	15
B_1 and T..........	28	35	28	9
B_3 and T..........	80	10	10	0
B_1, B_3 and B_{12}....	23	0	22	55
B_3, T and B_{12}.....	92	0	0	8
B_1, B_3 and T......	15	55	14	16
B_1, B_3, B_{12} and T.	15	0	0	85

[1] B_1 (Thiamine), B_3 (Biotin), B_{12} (Cobalamin), T (Trace element group)

"Aged sea water collected from an area of G. breve bloom will substitute for the group of trace elements. The addition of twenty milliliters of this water per liter of medium will support growth of G. breve when used to replace the trace elements. These results indicate that this water contains a relatively high concentration of the required group.

"These elements, with the possible exception of zirconium, are normally present in sea water, and their absence would probably not be a limiting factor for red tides. The form and higher concentrations of these elements may be a limiting factor of red tides. We must add metal chelators or metal

complexing substances to prepare a suitable sea water medium for G. breve, in most instances. Therefore, the occurrence of natural metal chelators or metal complexing substances may be necessary for red tides to develop." [p. 74.]

WILSON, WILLIAM B.
1960. Red tide investigation. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 39. U.S. Fish Wildl. Serv., Circ. 92.

Summary of fiscal year progress given in detail in other reports.

WILSON, WILLIAM B., and ALBERT COLLIER.
1955. Preliminary notes on the culturing of Gymnodinium brevis Davis. Science 121(3142):394-395.

". . . Titanium and zirconium were added to the mixture, although they are not normally present in measurable amounts in sea water, because these metals were found abundantly in water of G. brevis blooms. [p. 394.]

. . . . .

"Laboratory cultures of G. brevis have attained homogeneous concentrations exceeding 2 million cells per liter. This concentration is far below the highest report; however, the values cannot be compared. Among other reasons, G. brevis in cultures concentrate to form masses that we disperse by shaking before making counts. A similar tendency to concentrate, but on a larger scale, may be expected in nature. Counts of a sample from such a concentration would be high. . . ." [p. 395.]

WILSON, W. B., and S. M. RAY.
1956. The occurrence of Gymnodinium brevis in the western Gulf of Mexico. Ecology 37(2):388.

From 1953 to 1955 sea-water samples were collected at Galveston and along the Gulf coast between Galveston and Florida, but no G. brevis were observed.

In September 1955, 12 samples in about 20 square miles from the mouth of the Rio Grande to 10 miles N. of Port Isabel all contained from 50 to 500 G. brevis per ml. One sample near Port Isabel in the Laguna Madre contained no G. breve. Dead fish were on Gulf beaches from Rio Grande to 17 miles N. of Port Isabel.

C. E. Dawson and Henry Hildebrand checked by air south of the Rio Grande and observed dead fish at several points. One water sample taken 36 miles south of the Rio Grande contained over 22,000 per ml. At least 120 miles of the Tamaulipas coast was affected; fish were still dying on September 27, 1955.

WILSON, W. B., and SAMMY RAY.
1958. Nutrition of red tide organisms. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 62-65.

Discusses the development and gives the formula for an artificial sea water medium for growing bacteria-free cultures of G. brevis.

"G. breve requires phosphorus for growth in this artificial medium, but the absolute amount needed for growth has not been determined because the major salts contain phosphorus as an impurity. Cultures grew well without adding phosphorus until we recrystallized the sodium chloride to increase its purity. Increasing the phosphorus additions above the minimum amount necessary for growth does not increase the number of organisms. The addition of 0.1 microgram atom of phosphate phosphorus per liter (0.1 μg.at. P/L) is sufficient to support good growth. Chemical analyses of the medium for total phosphorus with this amount added indicate that it contains between 0.1 and 1.0 μg.at. P/L. Therefore, the amount of phosphorus required for maximum growth in this medium is apparently about 1.0 μg.at. P/L or less. . . ." [p. 64.]

WOOD, E. J. F.
1954. Dinoflagellates in the Australian Region. Aust. J. Mar. Freshwater Res. 5(2):171-351.

Lists and describes each species. Diagrams of species are outline drawings. No Gymnodinium listed. He speculated on correlation of Gonyaulax digitale with the new moon, but the evidence presented is not conclusive.

WOOD, E. J. F.
1963. Dinoflagellates in the Australian Region. II. Recent collections. Commonwealth Sci. Ind. Res. Org., Div. Fish. Oceanogr., Tech. Pap. 14, 55 p.

Describes 16 new species and lists over 190 species found since 1954. Lists 30 species of Gymnodinium.

WOODCOCK, ALFRED H.
1948. Note concerning human respiratory irritation associated with high concentrations of plankton and mass mortality of marine organisms. J. Mar. Res. 7(1):56-62.

Shows that the red-tide water, when sprayed into the nostrils or when breathed as an aerosol, caused coughing and a burning sensation in the nose and throat. Such aerosols are formed when waves break on the beach.

Breathing through a 2-cm. pad of absorbent cotton prevented irritation.

Unconcentrated "red water" containing 56 million G. breve per liter retained its irritating qualities unimpaired after storage for several weeks.

The irritant passed through a fine bacteria filter (openings, 1 to 1.5 microns).

WOODCOCK, A. H.
1955. Bursting bubbles and air pollution. Sewage Ind. Wastes 27(10):1189-1192.

"At relative humidities commonly found over the sea, droplets of sea water of this size [2-200 μ] will evaporate quickly to form nuclei of about 1 to 45 μ in diameter. Such nuclei fall slowly (0.01 to 13 cm. per sec.), and atmospheric turbulence and winds cause them to be carried many miles and hundreds of feet into the air . . . . [p. 1189.]

. . . . .

"Microscopic examination of the aerosols from 'red water' revealed that their surface tension was much reduced, compared to the surface tension of droplets of relatively clear sea water, and that some of the droplets contained parts of plankton organisms. . . ." [p. 1191.]

ACKNOWLEDGMENTS

Many authors and publishers have permitted us to quote from their articles. Among the periodicals are Advances in Food Research, American Geophysical Union, American Journal of Science, Botanical Gazette, Economic Geology, Limnology and Oceanography, Science, Scientific American, The American Naturalist, The Geological Society of America, Inc., and The Journal of Protozoology.

SUBJECT INDEX TO SELECTED TOPICS

Appendix table 1.--Monthly rainfall (inches) for south Florida, 1910-60[1]

Month	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Jan....	1.07	0.77	5.04	1.89	2.82	5.30	1.00	0.65	2.86	1.84	1.68	0.63	1.44	0.70	4.00	4.64	5.48	0.34
Feb....	1.82	.00	2.22	4.05	2.41	3.30	1.23	1.37	.69	3.81	2.75	2.17	1.86	.78	3.31	1.71	1.23	2.13
Mar....	1.53	.15	3.27	4.41	1.17	1.91	.62	1.90	2.77	1.77	.70	2.59	.62	1.05	3.66	2.27	2.51	2.14
Apr....	.54	3.03	2.78	2.77	4.44	1.85	2.94	1.75	4.58	1.77	5.87	1.19	.53	2.49	2.77	1.94	4.48	1.73
May....	3.90	5.83	7.82	4.95	3.05	5.16	4.59	2.60	2.67	6.85	4.83	6.51	7.33	10.63	3.44	8.11	3.07	1.25
June...	9.29	5.19	15.43	4.93	4.86	6.42	7.19	6.87	5.90	7.97	5.86	3.66	7.82	9.24	5.72	7.39	9.21	5.33
July...	7.81	6.17	5.12	5.11	5.94	8.66	7.02	6.85	6.35	8.06	4.54	6.06	7.37	7.43	10.82	7.31	10.03	7.38
Aug....	8.31	6.70	4.84	7.74	6.26	7.17	6.75	7.60	5.36	6.04	5.74	4.48	8.20	7.26	5.00	9.01	8.95	7.16
Sept...	4.28	3.97	6.91	5.87	7.93	6.01	5.40	10.62	9.06	4.77	8.58	2.61	10.44	6.51	6.59	3.10	9.31	6.18
Oct....	1.38	4.74	4.59	2.73	5.06	8.46	4.93	4.65	5.26	2.15	3.06	12.19	10.68	2.46	13.49	2.12	2.36	4.40
Nov....	1.10	4.29	3.84	2.11	3.13	2.00	3.67	.36	1.91	3.14	4.09	2.17	2.43	.41	.30	4.22	2.15	.77
Dec....	.55	2.45	1.24	2.18	3.82	2.06	2.21	1.00	2.04	1.86	1.59	1.39	1.53	.56	.53	5.45	.44	.86

Month	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
Jan....	0.53	1.39	2.22	3.95	1.49	1.23	1.18	1.10	3.17	1.24	1.36	0.84	3.21	4.29	2.66	1.01	1.24	2.71
Feb....	1.27	0.76	3.65	1.62	0.87	1.70	3.38	1.40	6.50	4.14	0.98	.65	3.36	3.99	3.37	0.72	0.27	0.44
Mar....	2.84	1.63	6.58	5.07	2.66	3.31	3.11	0.53	5.62	4.71	1.25	1.21	4.30	3.52	4.48	3.76	3.72	.61
Apr....	3.22	2.21	4.72	5.89	1.50	5.84	4.43	4.76	1.54	3.82	.47	4.36	2.07	5.88	4.98	2.29	2.79	1.92
May....	4.12	5.93	6.42	3.37	8.41	3.58	8.92	2.77	4.99	3.55	4.22	5.39	2.66	1.47	3.62	5.60	3.75	1.31
June...	7.34	8.89	14.22	2.21	8.78	6.84	10.50	6.50	13.77	7.14	6.78	11.21	7.60	7.32	12.44	7.31	6.36	11.00
July...	8.15	7.87	4.57	5.04	3.44	10.18	6.81	7.35	5.85	7.01	8.87	7.43	6.89	10.87	4.79	9.48	8.13	10.06
Aug....	12.08	6.60	5.41	5.52	10.06	7.50	5.13	6.72	6.45	7.78	3.26	4.94	7.54	4.83	4.96	8.11	6.72	6.56
Sept...	12.12	13.42	9.50	8.02	5.80	9.03	7.01	10.97	6.31	6.90	6.02	6.46	11.22	6.81	5.38	5.23	4.57	10.66
Oct....	2.42	5.85	3.75	3.23	5.02	6.20	2.31	4.11	4.68	5.87	5.08	5.27	1.33	3.90	1.19	3.93	6.15	5.38
Nov....	.64	1.51	1.31	0.72	4.03	2.20	0.93	1.24	2.50	3.89	2.15	1.30	0.29	3.73	0.68	2.06	.37	1.32
Dec....	.68	2.51	3.17	1.58	.33	0.31	.66	2.31	1.39	0.81	.63	1.16	4.73	2.80	2.80	.64	.44	2.33

Month	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
Jan....	1.19	1.20	5.05	0.21	0.20	0.27	1.07	2.83	0.93	1.94	1.09	2.00	6.11	2.46	0.64
Feb....	2.31	3.24	0.63	.52	.77	2.02	4.49	2.32	2.13	1.24	1.06	4.39	2.07	2.39	4.14
Mar....	1.86	6.44	2.10	1.16	2.24	1.22	3.90	2.85	1.82	1.62	0.58	4.18	6.17	7.44	5.35
Apr....	0.41	4.39	3.90	3.05	2.34	6.11	1.39	4.31	5.44	1.87	2.91	5.80	2.77	2.85	4.19
May....	7.26	5.37	3.00	2.72	3.06	2.37	4.11	1.94	7.13	3.19	4.18	7.87	7.86	5.83	3.15
June...	8.04	12.61	3.10	9.70	4.31	5.45	4.17	9.60	9.54	8.58	4.11	5.51	6.01	12.38	7.31
July...	8.68	9.96	9.49	7.23	6.14	9.62	7.09	7.39	8.53	6.21	5.17	8.24	6.31	7.41	12.36
Aug....	6.34	7.64	8.51	11.71	7.22	6.72	7.66	9.48	4.98	5.46	7.34	8.94	5.77	7.34	6.86
Sept...	7.00	13.55	14.74	9.26	7.09	6.59	6.93	10.87	7.40	6.44	6.97	7.79	5.38	9.52	15.70
Oct....	2.94	7.20	4.68	3.35	8.42	6.63	10.42	7.98	3.44	3.04	6.62	3.46	4.61	9.08	4.65
Nov....	2.53	3.76	.93	1.46	1.07	2.86	1.12	3.57	2.79	0.88	.67	1.33	1.46	3.51	1.08
Dec....	1.59	1.67	1.37	3.62	2.43	.89	1.11	2.56	1.29	2.01	.47	3.16	4.69	1.55	.97

[1] Compiled by Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla., from U.S. Weather Bureau records.

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